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VERIFICATION OF TEMPERATURE AND THERMAL STRESS ANALYSIS COMPUTE--ETC(U)
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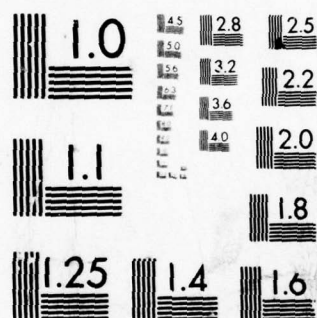
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VERIFICATION OF TEMPERATURE AND THERMAL STRESS ANALYSIS COMPUTER PROGRAMS FOR MASS CONCRETE STRUCTURES

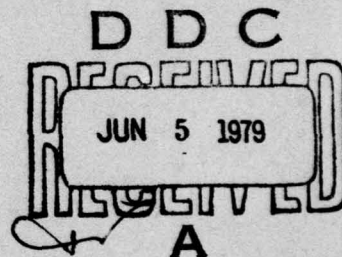
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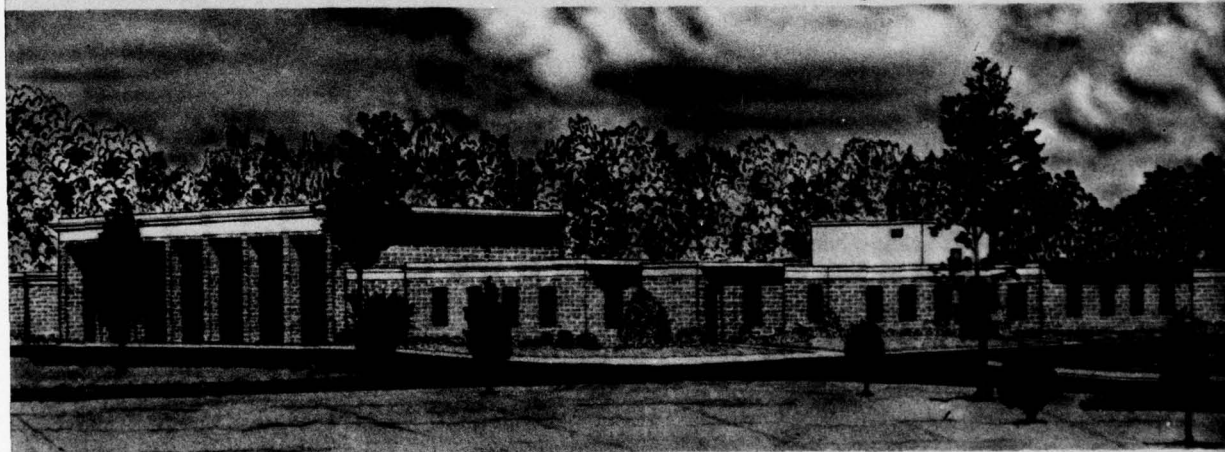
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Final Report

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The purpose of this investigation was to validate the accuracy and effective- ness of the temperature and thermal stress/strain calculation programs cur- rently being used by the Corps of Engineers by comparing analytical results with measured data obtained from embedded gages in Dworshak Dam. History of construction, weather data, and available material properties of Dworshak Dam were used for computer program input. (Continued)		

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20. ABSTRACT (Continued).

CONT

Based on the results of this investigation, it can be concluded that the temperature and thermal stress calculation programs currently being used by the Corps are acceptable. Recommendations for further improvement of these computer programs are presented.

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PREFACE

The work reported herein was conducted for the U. S. Army Engineer District, Walla Walla (NPW), by the Structures Laboratory (SL) of the U. S. Army Engineer Waterways Experiment Station (WES). Authorization for this investigation was given in DA Form 2544, dated 15 March 1978.

The material property information, construction history, instrumentation data, and the Walla Walla version of the temperature-calculation program used in this investigation were provided to WES by NPW and North Pacific Division Laboratory.

This investigation was performed under the direction of Messrs. B. Mather, J. M. Scanlon, and J. E. McDonald, SL. Dr. Tony C. Liu, Messrs. R. L. Campbell, and A. A. Bombich prepared this report.

The Commander and Director of WES during the conduct of this investigation and the preparation and publication of this report was COL J. L. Cannon, CE. Mr. F. R. Brown was Technical Director.

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CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiple	By	To Obtain
Btu · inch per hour · square inch · degree F	20.7688176	watts per metre · Kelvin
Btu per hour · square foot · degree Fahrenheit	5.678263	watts per square metre · Kelvin
Btu per pound (mass) · degree Fahrenheit	4186.8	joules per kilogram · Kelvin
calories per gram	4.184	kilojoules per kilogram
cubic yards	0.7645549	cubic metres
Fahrenheit degrees	5/9	Celsius degrees*
feet	0.3048	metres
inches	0.0254	metres
inches per degree Fahrenheit	0.014111111	metres per Kelvin
pounds (force) per square inch per minute	114.91267	pascals per second
pounds (force) per square inch (psi)	6894.757	pascals
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds per cubic yard	0.5932764	kilograms per cubic metre
square feet per hour	0.0000258064	square metres per second

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = C + 273.15$.

VERIFICATION OF TEMPERATURE AND THERMAL
STRESS ANALYSIS COMPUTER PROGRAMS FOR MASS CONCRETE STRUCTURES

PART I: INTRODUCTION

Background

1. Currently, two finite element computer programs are being used by the Corps to predict temperature distribution and resulting thermal stresses and strains in mass concrete structures. The first program,¹ developed by Dr. E. L. Wilson of the University of California (UC) at Berkeley, calculates temperatures within a mass concrete structure. The second program,² written by Dr. R. S. Sandhu, et al., also at UC Berkeley, calculates the thermal stresses and strains within the structure involving incremental construction and creep. These two computer programs are considered to be the most effective numerical methods for calculating temperature and thermal stresses/strains in the mass concrete structures. Because they are not only completely general with respect to geometry, material properties, and boundary conditions, but also provide the capability of simulating incremental construction and creep of mass concrete structures, these programs have been used for concrete temperature control studies for several Corps mass concrete structures, including Dworshak Dam. However, these programs have never been verified with actual field measured data.

2. As in many other dams, stress and strain meters, thermocouples, and other instruments were embedded in Dworshak Dam during construction to give information on structural behavior. Measurements have been obtained from these instruments since the beginning of construction in 1968. These measured data, together with the available laboratory information on concrete thermal and mechanical properties, provide a unique opportunity for verifying the computer programs.

Purpose and Scope

3. The purpose of this investigation was to verify the temperature and thermal stress/strain computer programs by comparing the analytical results with the measured data obtained from the embedded gages in the Dworshak Dam.

4. Because of the funding and time limitations, the analysis of the complete dam, taking full account of the time-varying thermal, elastic, and creep properties of concrete, was not considered possible. It was decided that the objective of this investigation could be achieved by analysis of the lower region of the Monolith 23, including foundation and 14 concrete lifts, during the period between 26 August 1968 and 15 February 1969.

5. History of construction, weather data, and available material properties of Dworshak Dam were used for computer program input. Calculated temperatures and stress/strain history were compared with the measured data. The validity and reliability of the computer programs are discussed, and recommendations for further development of temperature and thermal stress calculation programs are presented.

PART II: FINITE ELEMENT COMPUTER PROGRAMS

Temperature-Calculation Program

6. This program, developed by Dr. Wilson, calculates the temperature distribution as a function of time within a concrete structure as it is being constructed. Each lift of the structure may be placed at an arbitrary time and temperature. Insulating forms may be placed or removed from the surfaces. The external air temperature and temperature of the cooling water may also vary with time. The finite element technique coupled with a step-by-step time integration procedure is used as the method of analysis. Detailed discussion of this computer program is given in Reference 1.

7. Some input and output formats of Dr. Wilson's program were modified at WES for the convenience of the users. Both the WES and Walla Walla versions of the temperature-calculation program were used in this investigation and, as expected, the results were found to be identical. The WES version of temperature program is given in Appendix A.

Thermal Stress/Strain Calculation Program

8. This program, developed by Dr. Sandhu, calculates the displacements at each node and the strains and stresses developed in each element in the finite element model due to thermal, gravity, and other external loads. In allowing for creep, this program assumes that relaxation of stress takes place without nodal displacements over a small time increment during which the material properties do not change. This change in stress is then neutralized by releasing the constraints and treating the stress changes as residual stresses. Detailed discussion of this program is given in Reference 2.

9. In Dr. Sandhu's original program,² only one arbitrary reference temperature (stress-free temperature) was specified for all elements. The stress-free temperature input was modified in the WES version of the thermal stress program in which the stress-free temperature for an element is defined as the temperature at 8 hr after placement.

The stress-free temperatures for all elements are calculated in the WES version of the temperature calculation program and stored on disc file for subsequent input to the thermal stress analysis.

10. The WES version of the thermal stress analysis program was used in this investigation (Appendix B).

PART III: DETERMINATION OF CONCRETE TEMPERATURES

Finite Element Model

11. The finite element model selected for this investigation is representative of a small interior portion of Monolith 23. Figure 1 shows the typical cross section of Monolith 23 and Figure 2, the typical cooling pipe arrangement. Due to considerations of symmetry, only a 30-in.* wide slice was analyzed as shown in Figure 2.

12. The height of the finite element model was 80 ft (from El 930 to El 1010), representing 10 ft of foundation and 14 lifts of concrete at 5 ft per each lift. The plan of the model was located at 330 ft from the construction base line and center of the monolith. The finite element model, consisting of 576 nodes and 475 elements, is shown in Figure 3.

13. Except for the top concrete surfaces, all boundary conditions were assumed to be adiabatic because negligible boundary heat flow was expected in the interior portion of a mass concrete structure.

Material Types

14. Four adjustments in fly ash and cement contents in the concrete mixtures were made between August and December of 1968. Variations in concrete mixtures would affect the thermal and mechanical properties of concrete. Therefore, five material types (one foundation material and four concrete materials) were used in the analysis. A summary of material types used is given in Table 1.

* A table of factors for converting U.S. customary units of measurement to metric (SI) units is given on page 3.

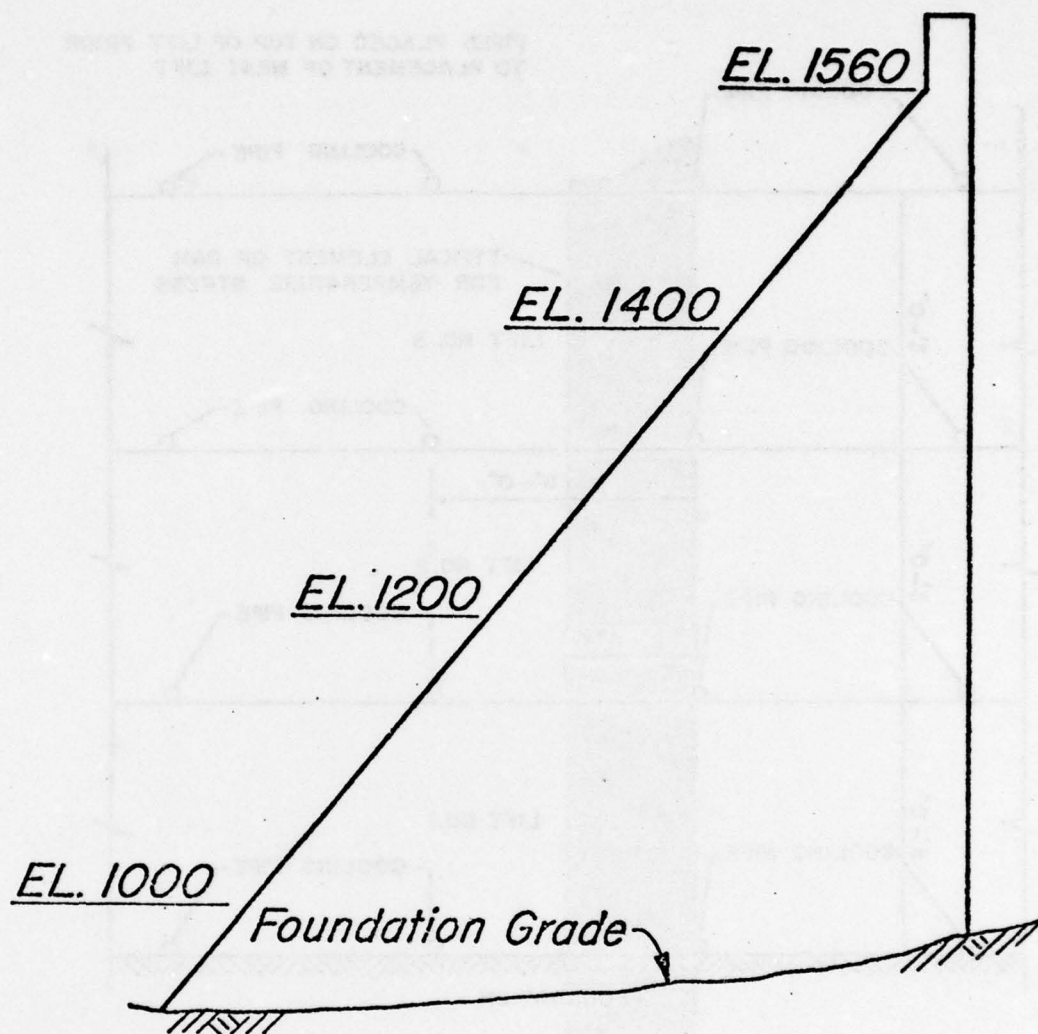


Figure 1. Cross Section of Monolith 23

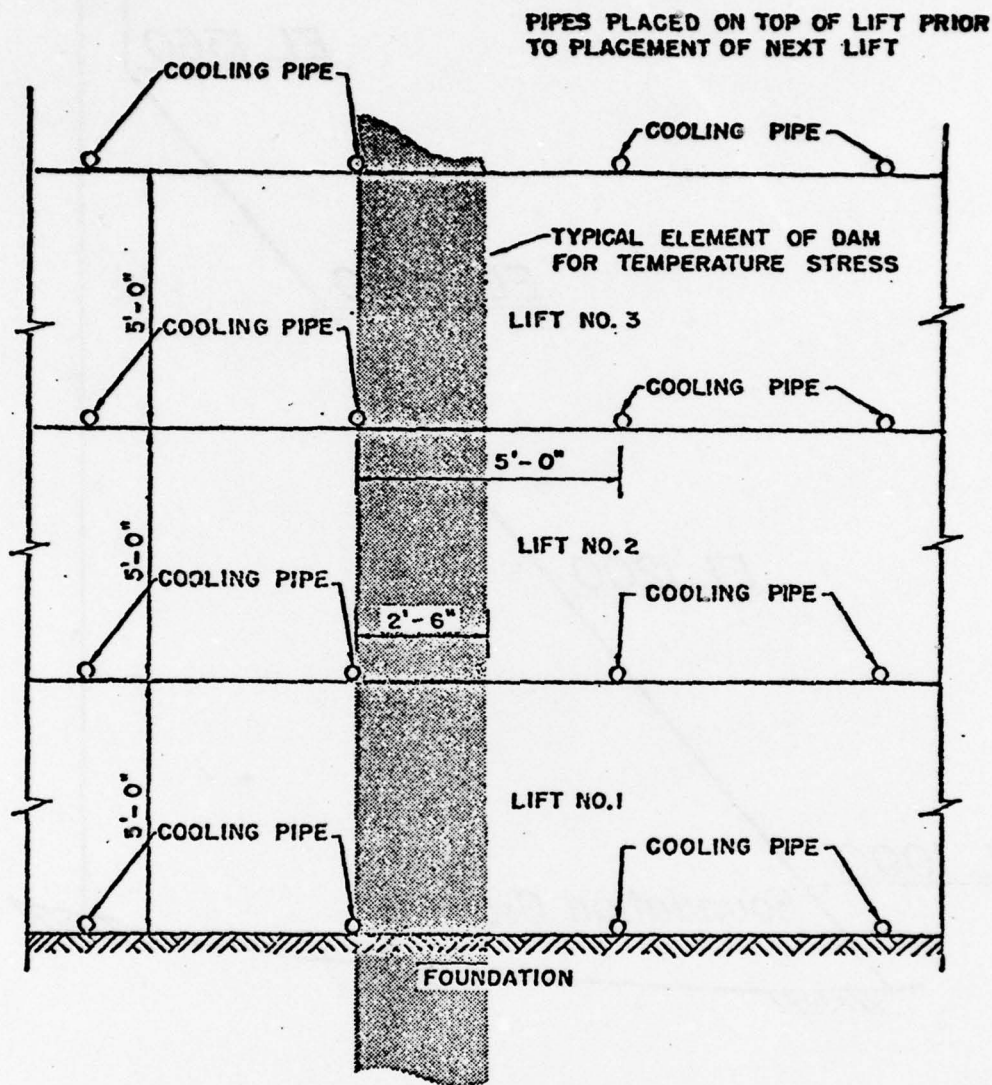


Figure 2. Typical Arrangement of Cooling Pipes

XL : -0.3000E 01
 XR : 0.3100E 02
 YL : -0.3000E 01
 YU : 0.6300E 02



XL : -0.3000E 01
 XR : 0.3300E 02
 YL : 0.5700E 02
 YU : 0.1230E 03

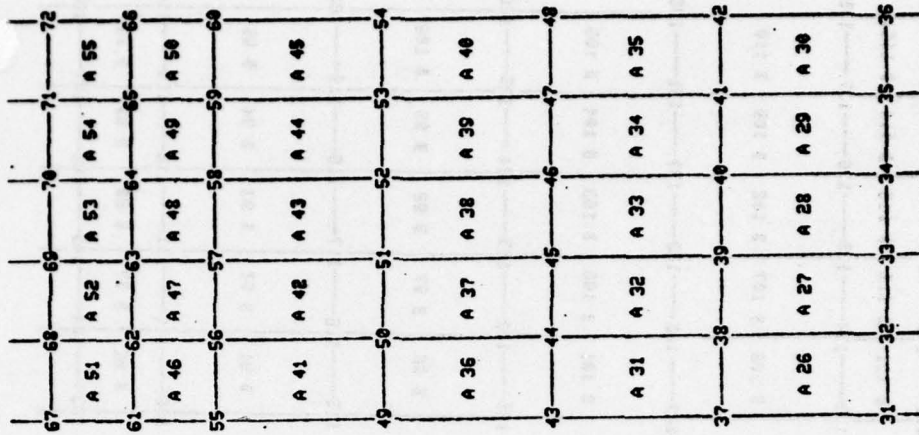
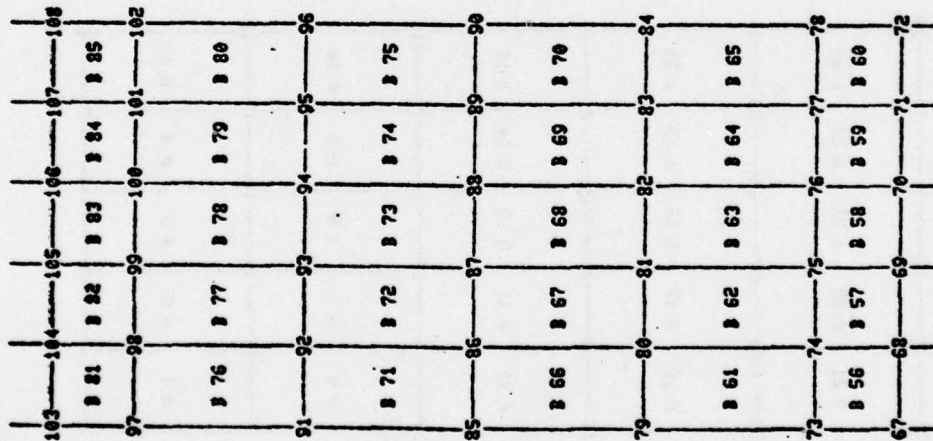


Figure 3. Finite Element Model

XL : -0.3000E 01
 XR : 0.3700E 02
 YL : 0.1700E 03
 YU : 0.1830E 03



XL : -0.3000E 01
 XR : 0.3700E 02
 YL : 0.1770E 03
 YU : 0.2430E 03

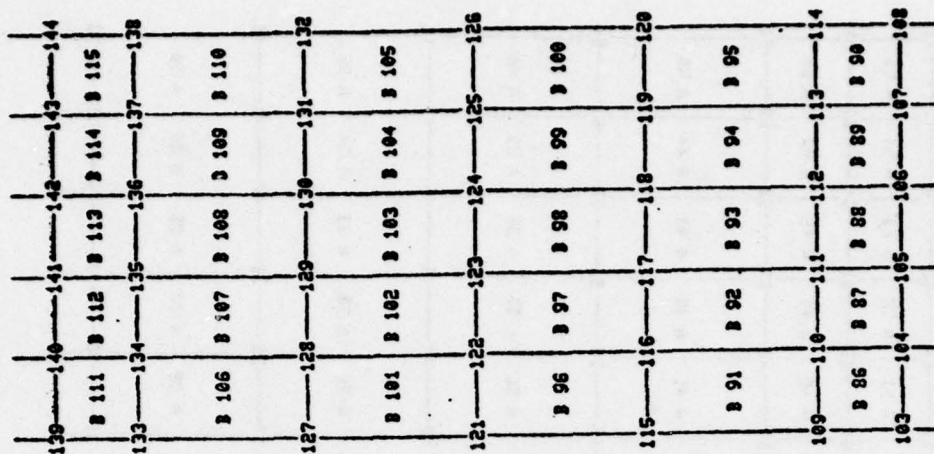
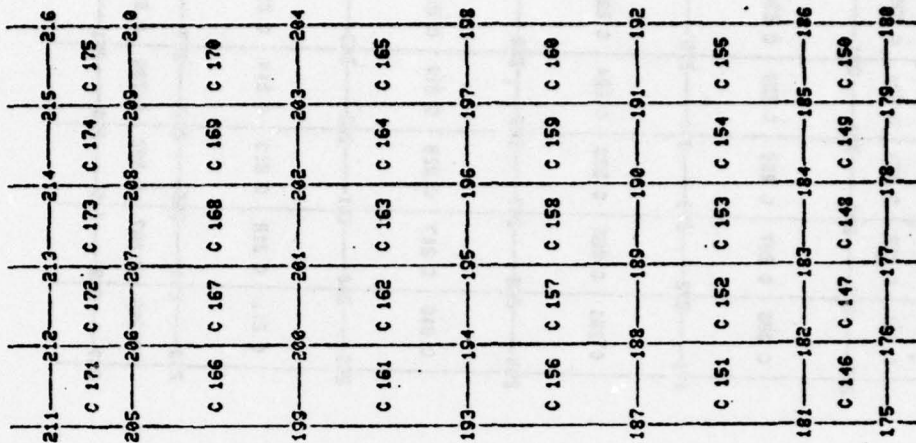


Figure 3 (Continued)

XL : -0.3000E 01
 XR : 0.3300E 02
 YL : 0.2970E 03
 YU : 0.3630E 03



XL : -0.3000E 01
 XR : 0.3300E 02
 YL : 0.2970E 03
 YU : 0.3630E 03

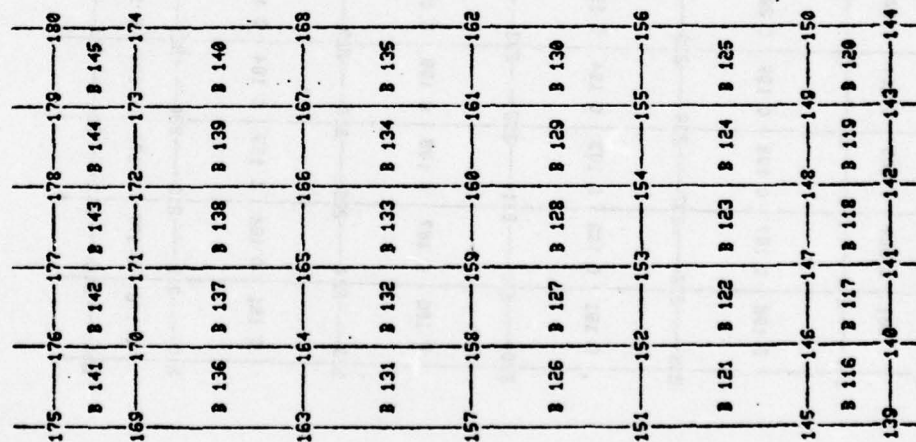


Figure 3 (Continued)

XL : -0.3000E 01
 XR : 0.1300E 03
 VL : 0.5570E 03
 VU : 0.4230E 03

247	248	249	250	251	252
C 201	C 202	C 203	C 204	C 205	
241	242	243	244	245	246
C 196	C 197	C 198	C 199	C 200	
235	236	237	238	239	240
C 191	C 192	C 193	C 194	C 195	
229	230	231	232	233	234
C 186	C 187	C 188	C 189	C 190	
223	224	225	226	227	228
C 181	C 182	C 183	C 184	C 185	
217	218	219	220	221	222
C 176	C 177	C 178	C 179	C 180	
211	212	213	214	215	216

XL : -0.3000E 01
 XR : 0.1300E 02
 VL : 0.4170E 03
 VU : 0.4830E 03

213	214	215	216	217	218
C 231	C 232	C 233	C 234	C 235	
277	278	279	280	281	282
C 226	C 227	C 228	C 229	C 230	
271	272	273	274	275	276
C 221	C 222	C 223	C 224	C 225	
265	266	267	268	269	270
C 216	C 217	C 218	C 219	C 220	
259	260	261	262	263	264
C 211	C 212	C 213	C 214	C 215	
253	254	255	256	257	258
C 206	C 207	C 208	C 209	C 210	
247	248	249	250	251	252

Figure 3 (Continued)

XL : -0.3000E 01
 XR : 0.3300E 02
 YL : 0.4700E 03
 YU : 0.5430E 03

319	320	321	322	323	324
C 261	C 262	C 263	C 264	C 265	
313	314	315	316	317	318
C 256	C 257	C 258	C 259	C 260	
307	308	309	310	311	312
C 251	C 252	C 253	C 254	C 255	
301	302	303	304	305	306
C 246	C 247	C 248	C 249	C 250	
295	296	297	298	299	300
C 241	C 242	C 243	C 244	C 245	
289	290	291	292	293	294
C 236	C 237	C 238	C 239	C 240	
283	284	285	286	287	288

XL : -0.3000E 01
 XR : 0.3300E 02
 YL : 0.5370E 03
 YU : 0.6030E 03

355	356	357	358	359	360
D 291	D 292	D 293	D 294	D 295	
349	350	351	352	353	354
D 286	D 287	D 288	D 289	D 290	
343	344	345	346	347	348
D 281	D 282	D 283	D 284	D 285	
337	338	339	340	341	342
D 276	D 277	D 278	D 279	D 280	
331	332	333	334	335	336
D 271	D 272	D 273	D 274	D 275	
325	326	327	328	329	330
D 266	D 267	D 268	D 269	D 270	
319	320	321	322	323	324

Figure 3 (Continued)

XL : -0.3000E 01
 XR : 0.3100E 02
 VL : 0.6570E 03
 VU : 0.7230E 03

427	428	429	430	431	432
D 351	D 352	D 353	D 354	D 355	
421	422	423	424	425	426
D 346	D 347	D 348	D 349	D 350	
415	416	417	418	419	420
D 341	D 342	D 343	D 344	D 345	
409	410	411	412	413	414
D 336	D 337	D 338	D 339	D 340	
403	404	405	406	407	408
D 331	D 332	D 333	D 334	D 335	
397	398	399	400	401	402
D 326	D 327	D 328	D 329	D 330	
391	392	393	394	395	396

XL : -0.3000E 01
 XR : 0.3100E 02
 VL : 0.6570E 03
 VU : 0.7230E 03

381	382	383	384	385	386
D 321	D 322	D 323	D 324	D 325	
385	386	387	388	389	390
D 316	D 317	D 318	D 319	D 320	
379	380	381	382	383	384
D 311	D 312	D 313	D 314	D 315	
373	374	375	376	377	378
D 306	D 307	D 308	D 309	D 310	
367	368	369	370	371	372
D 301	D 302	D 303	D 304	D 305	
361	362	363	364	365	366
D 296	D 297	D 298	D 299	D 300	
355	356	357	358	359	360

Figure 3 (Continued)

XL : -0.3000E 01
 XR : 0.3300E 02
 YL : 0.7170E 03
 YU : 0.7830E 03

483	464	465	466	467	468
D 381	D 382	D 383	D 384	D 385	
457	458	459	460	461	462
D 376	D 377	D 378	D 379	D 380	
451	452	453	454	455	456
D 371	D 372	D 373	D 374	D 375	
445	446	447	448	449	450
D 366	D 367	D 368	D 369	D 370	
439	440	441	442	443	444
D 361	D 362	D 363	D 364	D 365	
433	434	435	436	437	438
D 356	D 357	D 358	D 359	D 360	
427	428	429	430	431	432

XL : -0.3000E 01
 XR : 0.3300E 02
 YL : 0.7770E 03
 YU : 0.8430E 03

499	500	501	502	503	504
B 411	B 412	B 413	B 414	B 415	
493	494	495	496	497	498
B 406	B 407	B 408	B 409	B 410	
487	488	489	490	491	492
B 481	B 482	B 483	B 484	B 485	B 486
481	482	483	484	485	486
B 396	B 397	B 398	B 399	B 400	
475	476	477	478	479	480
B 391	B 392	B 393	B 394	B 395	
469	470	471	472	473	474
B 386	B 387	B 388	B 389	B 390	
463	464	465	466	467	468

Figure 3 (Continued)

XL : -0.3000E 01
 XR : 0.3000E 02
 VL : 0.8970E 03
 VU : 0.9630E 03

535	536	537	538	539	540
E 441	E 442	E 443	E 444	E 445	
529	530	531	532	533	534
E 436	E 437	E 438	E 439	E 440	
523	524	525	526	527	528
E 431	E 432	E 433	E 434	E 435	
517	518	519	520	521	522
E 426	E 427	E 428	E 429	E 430	
511	512	513	514	515	516
E 421	E 422	E 423	E 424	E 425	
505	506	507	508	509	510
E 416	E 417	E 418	E 419	E 420	
499	500	501	502	503	504

XL : -0.3000E 01
 XR : 0.3000E 02
 VL : 0.8970E 03
 VU : 0.9630E 03

571	572	573	574	575	576
E 471	E 472	E 473	E 474	E 475	
565	566	567	568	569	570
E 466	E 467	E 468	E 469	E 470	
559	560	561	562	563	564
E 461	E 462	E 463	E 464	E 465	
553	554	555	556	557	558
E 456	E 457	E 458	E 459	E 460	
547	548	549	550	551	552
E 451	E 452	E 453	E 454	E 455	
541	542	543	544	545	546
E 446	E 447	E 448	E 449	E 450	
535	536	537	538	539	540

Figure 3 (Concluded)

Thermal Properties of Concrete and Foundation

15. The thermal properties of concrete and foundation required by the temperature calculation program are (a) specific heat, (b) density, (c) thermal conductivity, and (d) adiabatic temperature rise versus age. The values of thermal properties used in the analysis are given in Tables 2 and 3.

16. The specific heat, density, and thermal conductivity of material Type 2 were obtained from the test results of mixture No. A-2 reported in Appendix C of Reference 4. The thermal properties of other concrete material types used in the analysis were interpolated from the available test data given in Reference 4. The thermal properties of foundation material (material Type 1) were assumed to be identical to material Type 2.

17. The adiabatic temperature rise data presented in Table 3 were derived from the test results given in page 2.3-9 of Reference 4. The adiabatic temperature rise data beyond 28 days were obtained by extrapolation of the available data on a semi-logarithmic plot.

Construction Parameters

Ambient temperatures

18. The mean daily ambient temperature at Dworshak Dam from 26 August 1968 to 15 February 1969, during which the construction is being simulated, is plotted in Figure 4. This information was provided by the Walla Walla District. The simplified ambient exposure temperatures used in the analysis are shown in Figure 5.

Foundation temperature

19. In order to simulate the foundation temperatures in the model, the temperature of the entire foundation was first set equal to 65°F. It was assumed that the temperature at the bottom of the foundation would remain constant throughout the analysis period. Prior to the beginning of construction simulation, the surface of the foundation was exposed to

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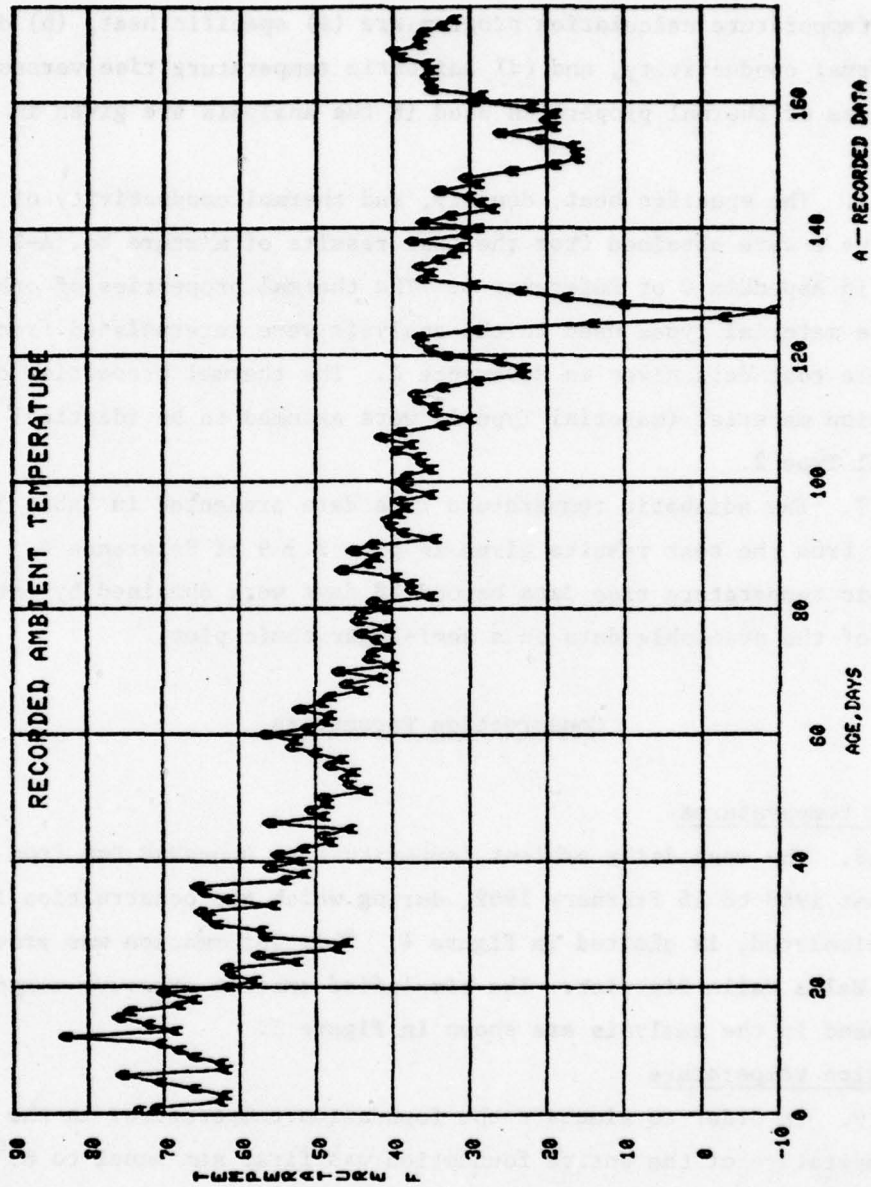


Figure 4. Mean Daily Ambient Temperatures, Dworshak Dam

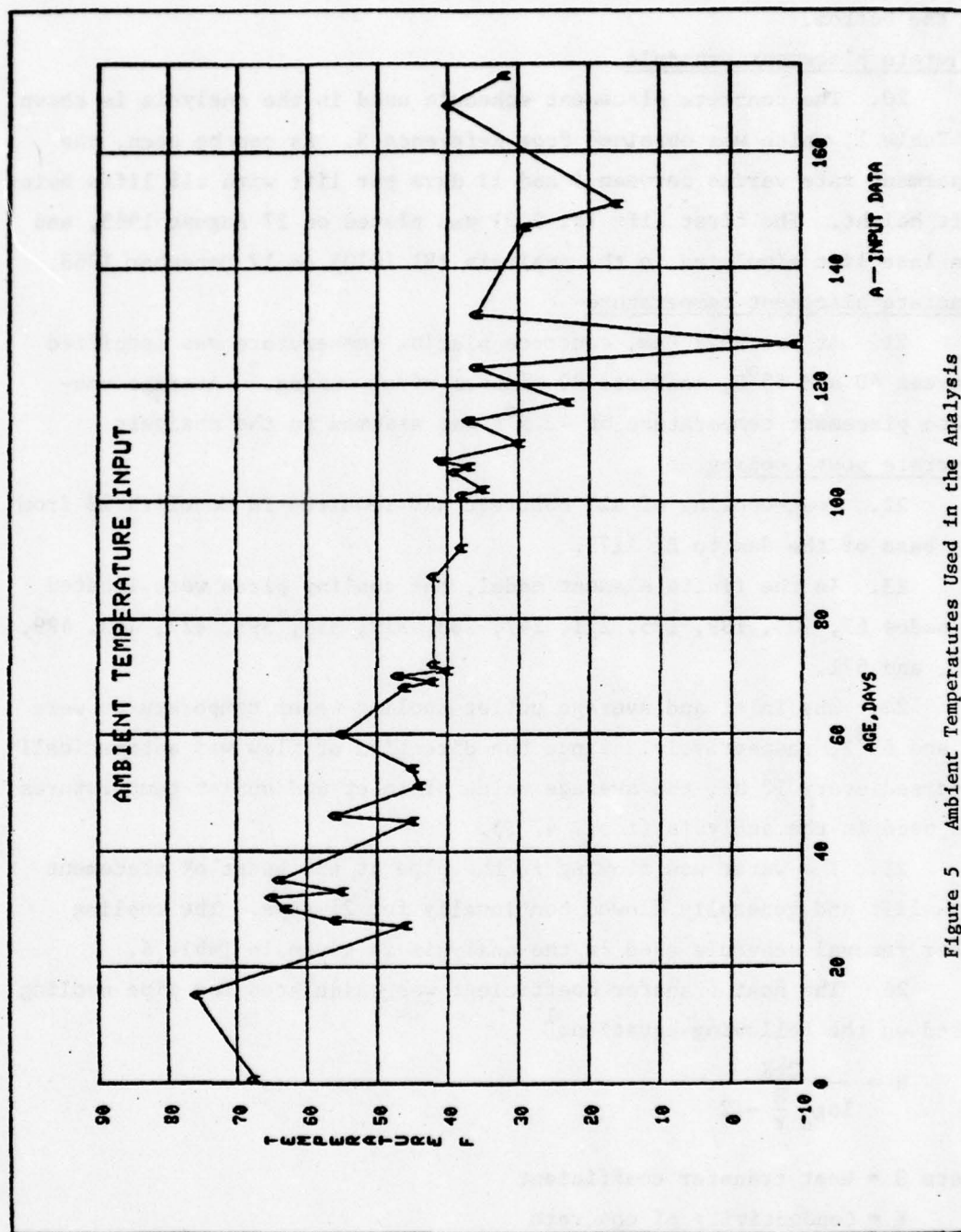


Figure 5 Ambient Temperatures Used in the Analysis

ambient temperature and calculation was made to equilibrate foundation temperatures between ambient at the surface and the constant temperature at the bottom.

Concrete placement schedule

20. The concrete placement schedule used in the analysis is shown in Table 1, which was obtained from Reference 3. As can be seen, the placement rate varied between 4 and 13 days per lift with all lifts being 5-ft height. The first lift (El 940) was placed on 27 August 1968, and the last lift simulated in the analysis (El 1010) on 17 December 1968.

Concrete placement temperature

21. At Dworshak Dam, concrete placing temperature was specified between 40 and 45°F, measured 20 minutes after mixing.³ Average concrete placement temperature of 42.5°F was assumed in the analysis.

Concrete post-cooling

22. Post-cooling of all concrete was required in Monolith 23 from the base of the dam to El 1175.

23. In the finite element model, the cooling pipes were located at nodes 67, 103, 139, 175, 211, 247, 283, 319, 355, 391, 427, 463, 499, 535, and 571.

24. The inlet and average outlet cooling water temperatures were 41 and 53°F, respectively. Since the direction of flow was automatically reversed every 12 hr, the average value of inlet and outlet temperatures was used in the analysis (i.e., 47°F).

25. The water was flowing in the pipe at the start of placement in a lift and generally flowed continually for 21 days. The cooling water removal schedule used in the analysis is given in Table 4.

26. The heat transfer coefficient was calculated for pipe cooling based on the following equation:¹

$$H = \frac{2\pi K}{\log_e \frac{R}{r} - 2}$$

where H = Heat transfer coefficient

K = Conductivity of concrete
= 0.113 Btu/hr-in.-°F

R = Mesh size in the vicinity of the pipe
= 6 in.

r = Radius of cooling pipe
= 0.5 in.

Because of symmetry at the cooling pipes, the mathematical model (Figure 2) included only concrete elements from the pipe location to a distance half-way to the next cooling pipe. Therefore, half of the calculated H value was used in the program calculations.

Surface insulation

27. During construction, the top lift surface was generally covered with insulating mats immediately after placing. The insulation remained in place until the lift surface was to be covered with concrete, except for the time during which the joint was cleaned with high-pressure water jet.

28. The thermal conductivities of insulation materials used in the analysis are shown in Table 5.³

Wind velocities

29. In order to compute the convection transfer coefficient, wind velocity data are required. The wind data used in the analysis were obtained from Dworshak Station and are summarized in Table 6.

Heat transfer coefficients

30. The surface heat transfer coefficients used in the analysis were calculated according to the following equation;¹

$$H = \frac{1}{\frac{1}{c} + \frac{1}{h'}}$$

where H = Heat transfer coefficient

c = Conductance of insulation

h' = Convection transfer coefficient

= $0.99 + 0.21V$ for $V < 16$ fps*

V = wind velocity

* From ASHRAE Handbook, 1977 Fundamentals.

31. Based on the data given in Tables 5 and 6, the surface heat transfer coefficients used in the analysis are summarized in Table 7.

Results and Discussion

32. The analysis was performed for 174 days, from 26 August 1968 to 15 February 1969. Calculated temperatures were output at one-day intervals for all nodes in the model at the particular stage of construction.

33. In general, peak temperatures of approximately 66°F were attained after about five days. Placing of precooled overlying lifts resulted in lower temperatures subsequent to their placement. After attainment of peak temperature, the temperature of a lift dropped as long as cooling was continued. When cooling of a lift was stopped at 21 days but continued on the overlying lifts, the temperature rose gradually to approximately the primary peak at about 40 days, and this temperature remained essentially constant throughout the remaining analytical period. The comparisons between calculated and measured temperatures are made at nodes 198, 342, and 486, where thermocouples 2309B, 2319B, and 2329B, respectively, are located. As can be seen from Figures 6, 7, and 8, excellent agreements between calculated and measured temperatures are obtained. The average differences between calculated and measured temperatures were 0.80°F , 1.56°F , and 1.57°F for nodes 198, 342, and 486, respectively. These small discrepancies were due probably to the following reasons.

- a. The adiabatic temperature rise data used in the analysis were based on the 28-day test results. It is obvious that heat is still being generated for an extended period of time after the 28-day adiabatic temperature rise test period. The adiabatic temperature rise data beyond 28 days were assumed in the analysis because this information was not available.
- b. Average concrete placement temperature of 42.5°F was assumed in the analysis. No record of actual concrete temperatures at placement was available.
- c. The average cooling water temperature was used in the analysis because the actual inlet and outlet cooling water temperatures were not available.

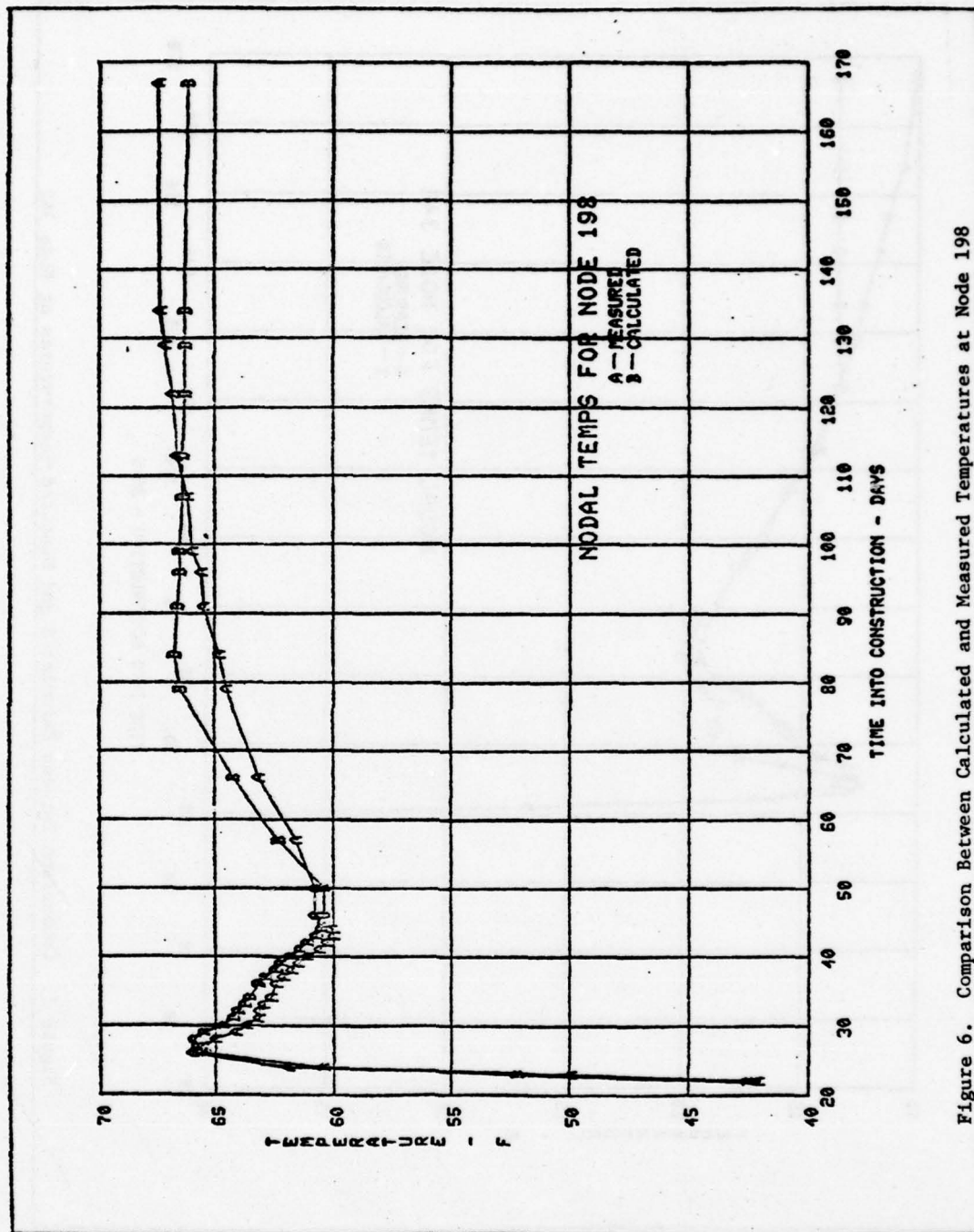


Figure 6. Comparison Between Calculated and Measured Temperatures at Node 198

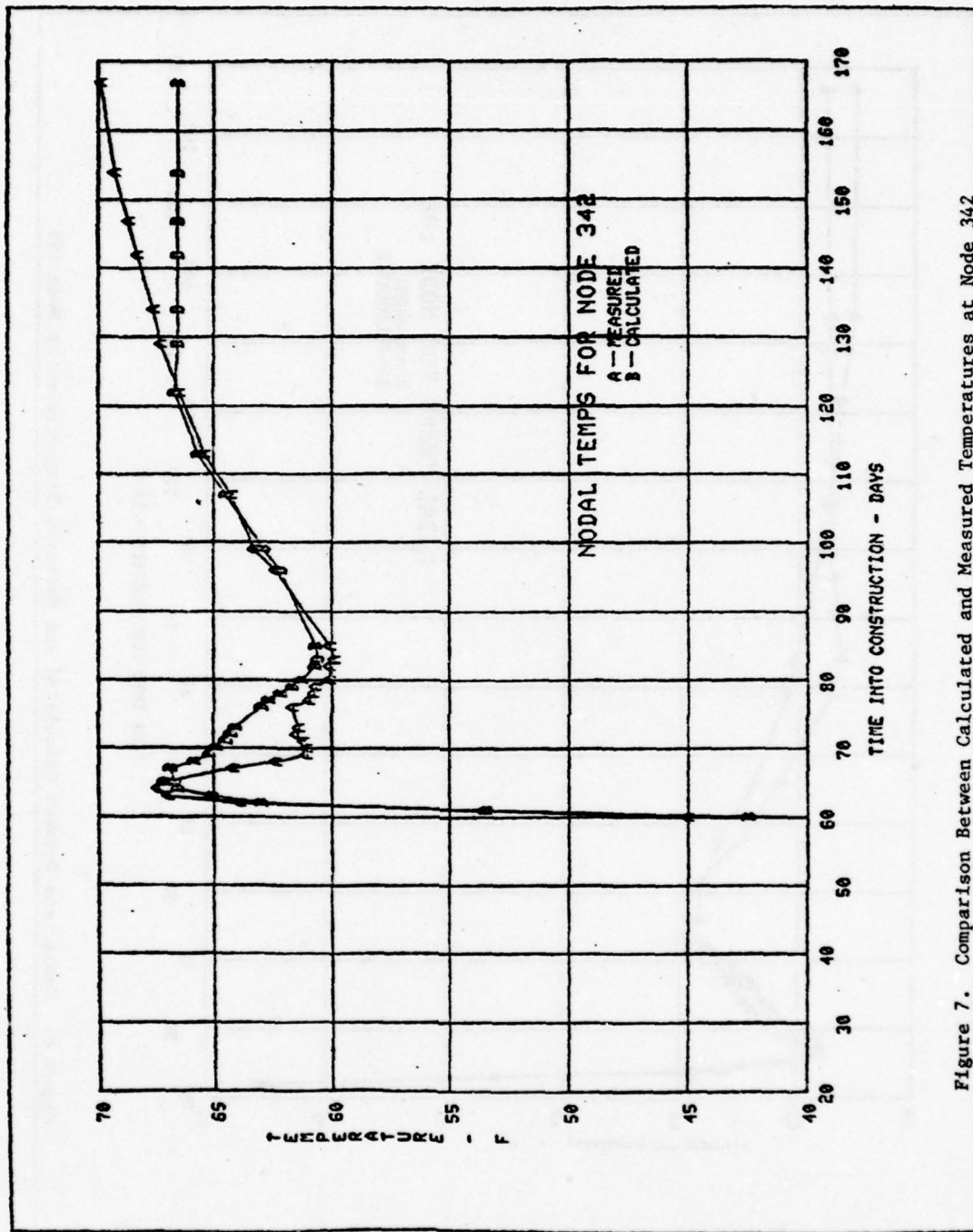


Figure 7. Comparison Between Calculated and Measured Temperatures at Node 342

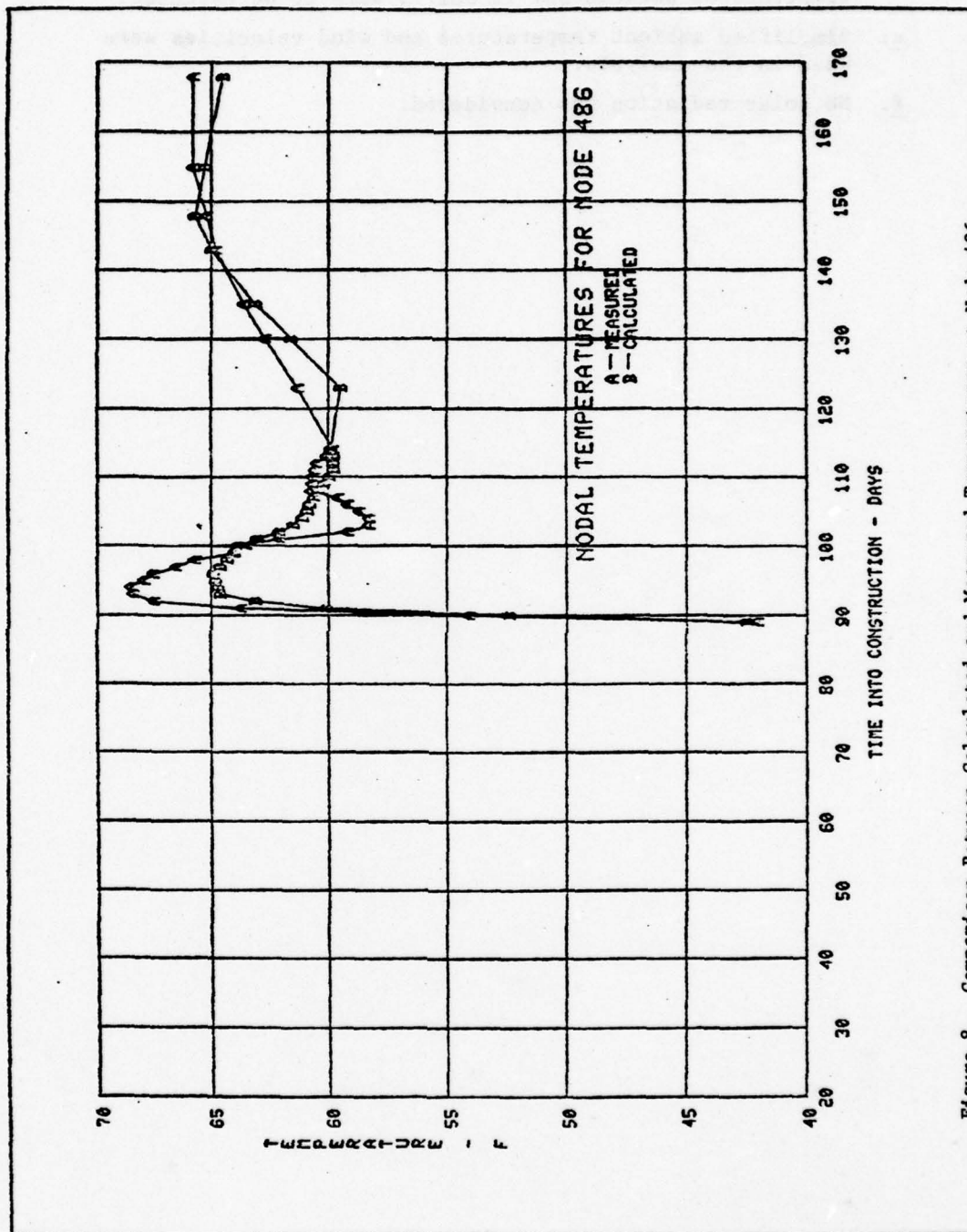


Figure 8. Comparison Between Calculated and Measured Temperatures at Node 486

- d. The thermocouple 2319B clearly indicated that the concrete cooling rate was too rapid at node 342 , and the water flow was interrupted between Day 70 and Day 75 (Figure 7). In the analysis, however, only the specified cooling flow was used. Discrepancies between measured and calculated temperatures between Day 70 and 75 were to be expected.
- e. Simplified ambient temperatures and wind velocities were used in the analysis.
- f. No solar radiation was considered.

PART IV: DETERMINATION OF THERMAL STRESSES

Finite Element Model

34. The same finite element model used in the temperature calculation program was used. Because of symmetry, no horizontal displacement at the vertical boundary was permitted and shear force was assumed to be zero. The nodal points at the bottom of the foundation were assumed fixed in all directions.

Properties of Concrete and Foundation

35. The properties of concrete and foundation required for the thermal stress analysis are (a) modulus of elasticity versus age, (b) Poisson's ratio versus age, (c) coefficient of thermal expansion, (d) shear foundation factor, and (e) creep versus age.

36. The values of modulus of elasticity, Poisson's ratio, and coefficient of thermal expansion are given in Tables 8 through 12. These values were derived from limited test data reported in Reference 4. All shear foundation factors are assumed to be zero.

37. The mathematical formulation of the creep mechanism used in the computer program was proposed originally by McHenry.⁵ It may be expressed as follows:

$$\epsilon_c(t) = \sigma \sum_{i=1}^n a_i(T) \{1 - e^{-m_i(t-T)}\}$$

where $\epsilon_c(t)$ = Creep strain

σ = Applied stress

t = Time after placement

T = Age at loading

$m_i, a_i(t)$ = Creep constants

38. McHenry suggested that a sufficient number of terms be included in this series to give satisfactory agreement with available experiment data. In the present study, it was assumed that two terms would

suffice. The function of $a_1(T)$ and $a_2(T)$ used in the analysis are given in Table 13. The values of m_1 and m_2 were 0.034 and 0.52, respectively. These creep constants were derived based on the results of the creep tests performed at UC Berkeley⁶ as reported in Reference 4.

Analysis Time Interval

39. In the analysis, the stress relaxation of the concrete within the finite elements was carried out by a time-increment sequence. Thus, it was necessary to establish time intervals short enough to give the desired accuracy but long enough to retain computational efficiency.

40. A total of 90 analysis times covering 26 August 1968 through 15 February 1969 was selected for the analysis.

Results and Discussion

41. A typical stress distribution is depicted in Figure 9, which shows the variation of horizontal stresses developed in three lifts. The figure indicates that between days 2 and 5, the horizontal compressive stresses in Lift 1 were gradually increased because of the increase in concrete temperatures. The maximum compressive stress was found near the center of the lift. When a cold new concrete lift was placed upon the relatively warm old lift, a sudden development of tensile stresses resulted at the lift interface. These stresses were gradually reduced because of creep and temperature rise due to hydration of cement. At Day 22, the tensile stress developed at the surface of Lift 3 was due to sudden ambient temperature drop at 16 September 1968 (see Figures 4 and 5).

42. The comparisons between calculated and measured strains are made at Element 235, where strain meters S052 and S053 are located. Figures 10 and 11 show the comparison between calculated and measured X-strains and Y-strains, respectively. The calculated stresses at Element 240 were compared with the stress meter Group AG G05 readings (Figures 12 and 13). Since the zero dates for stress and strain meters

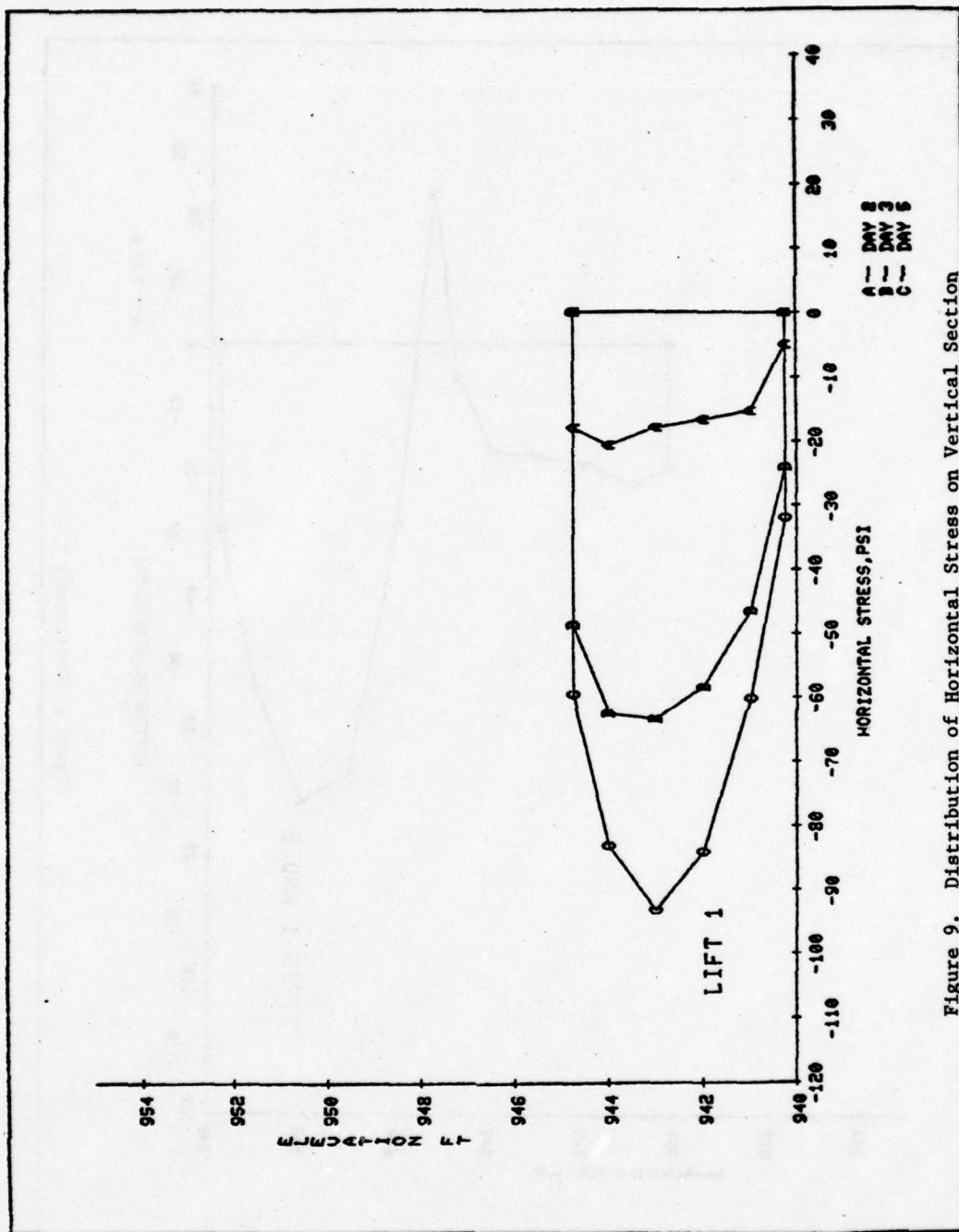


Figure 9. Distribution of Horizontal Stress on Vertical Section

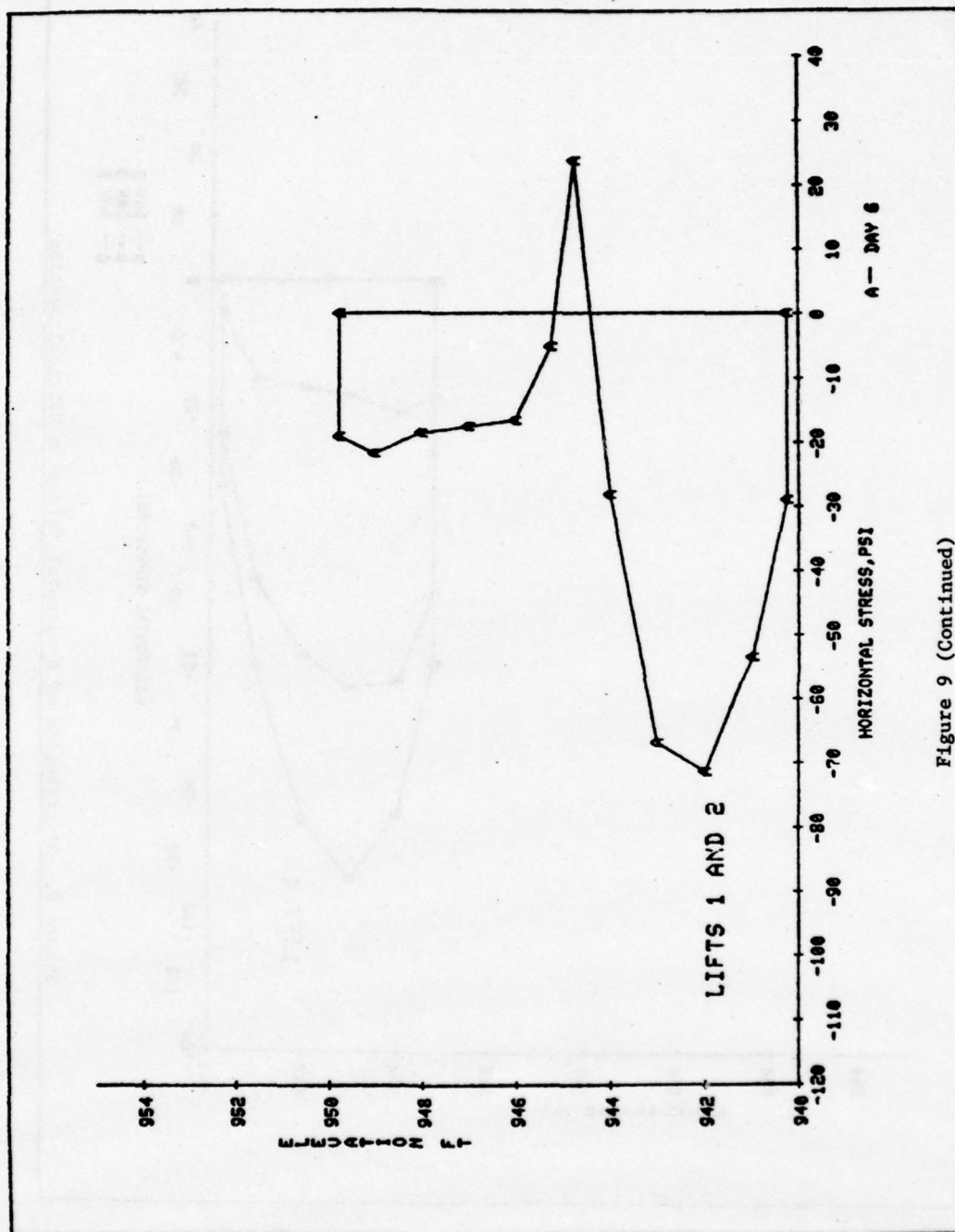


Figure 9 (Continued)

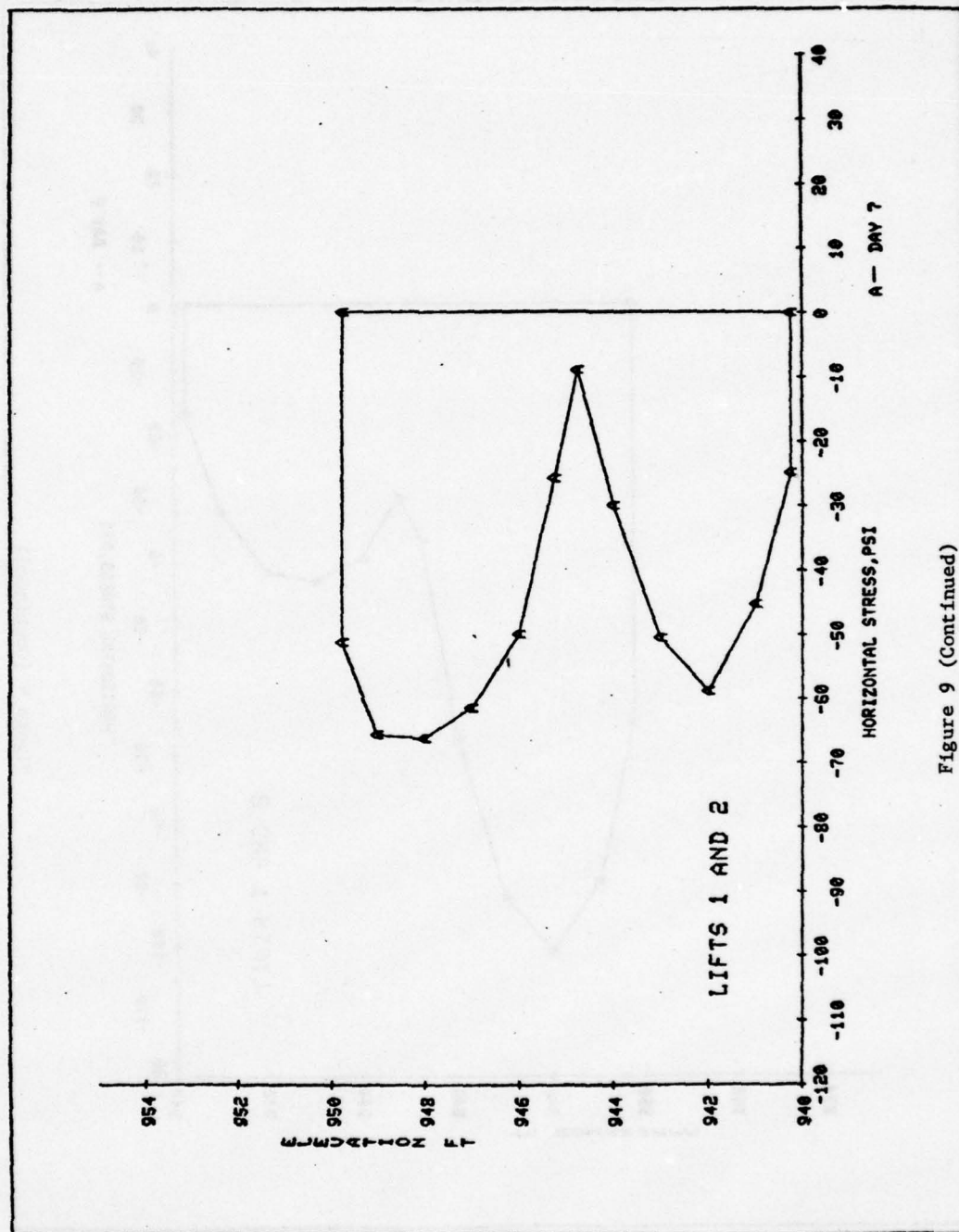


Figure 9 (Continued)

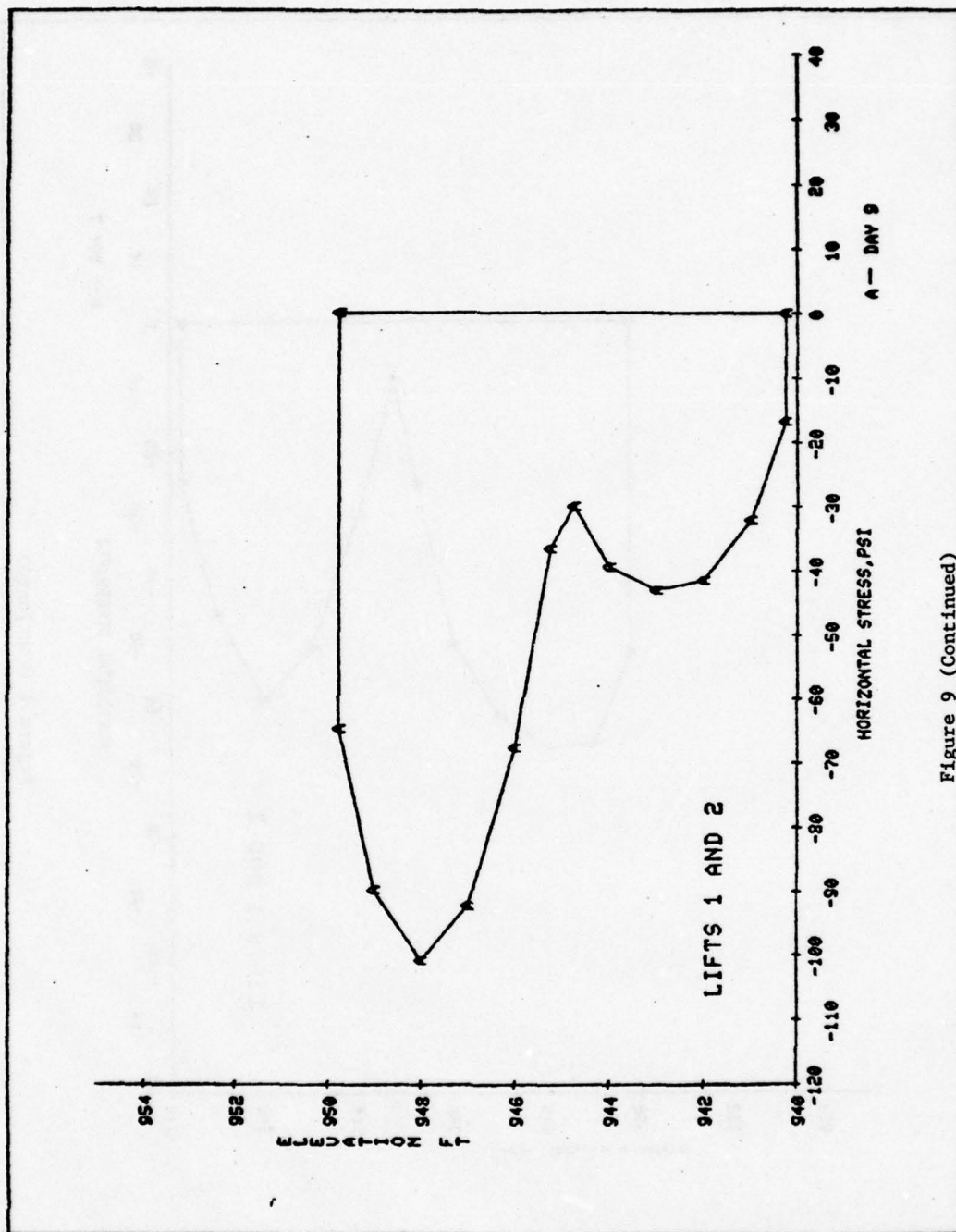


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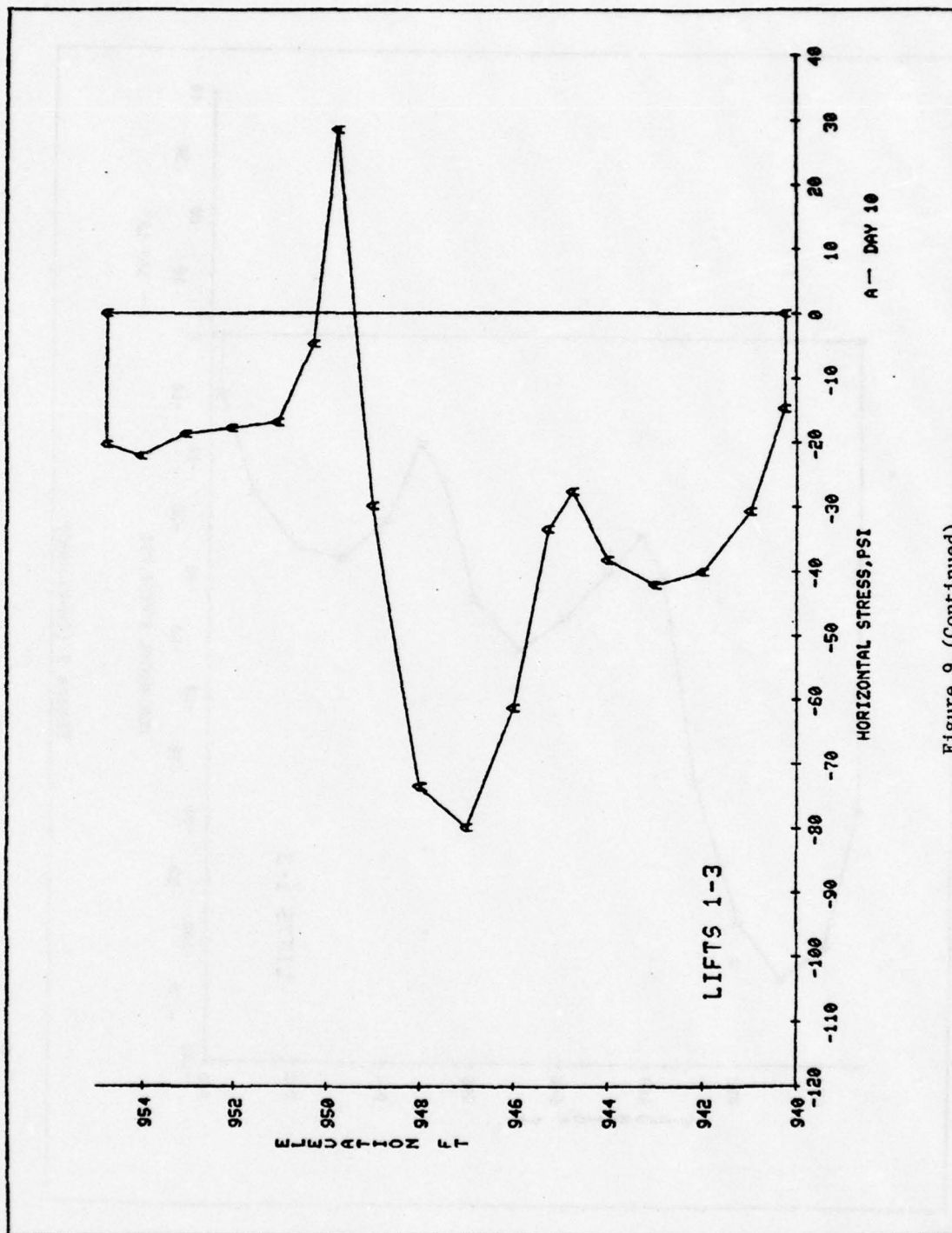


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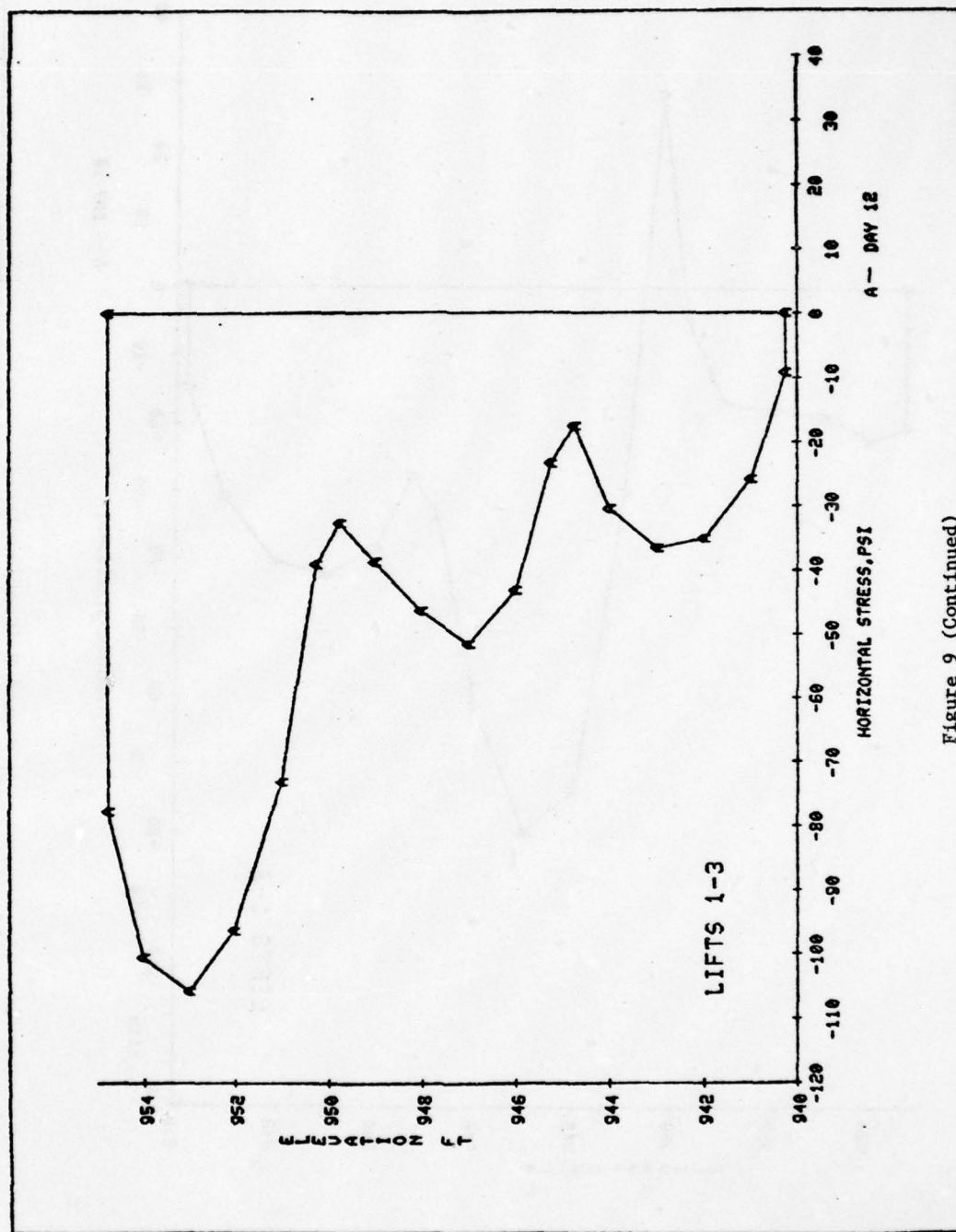


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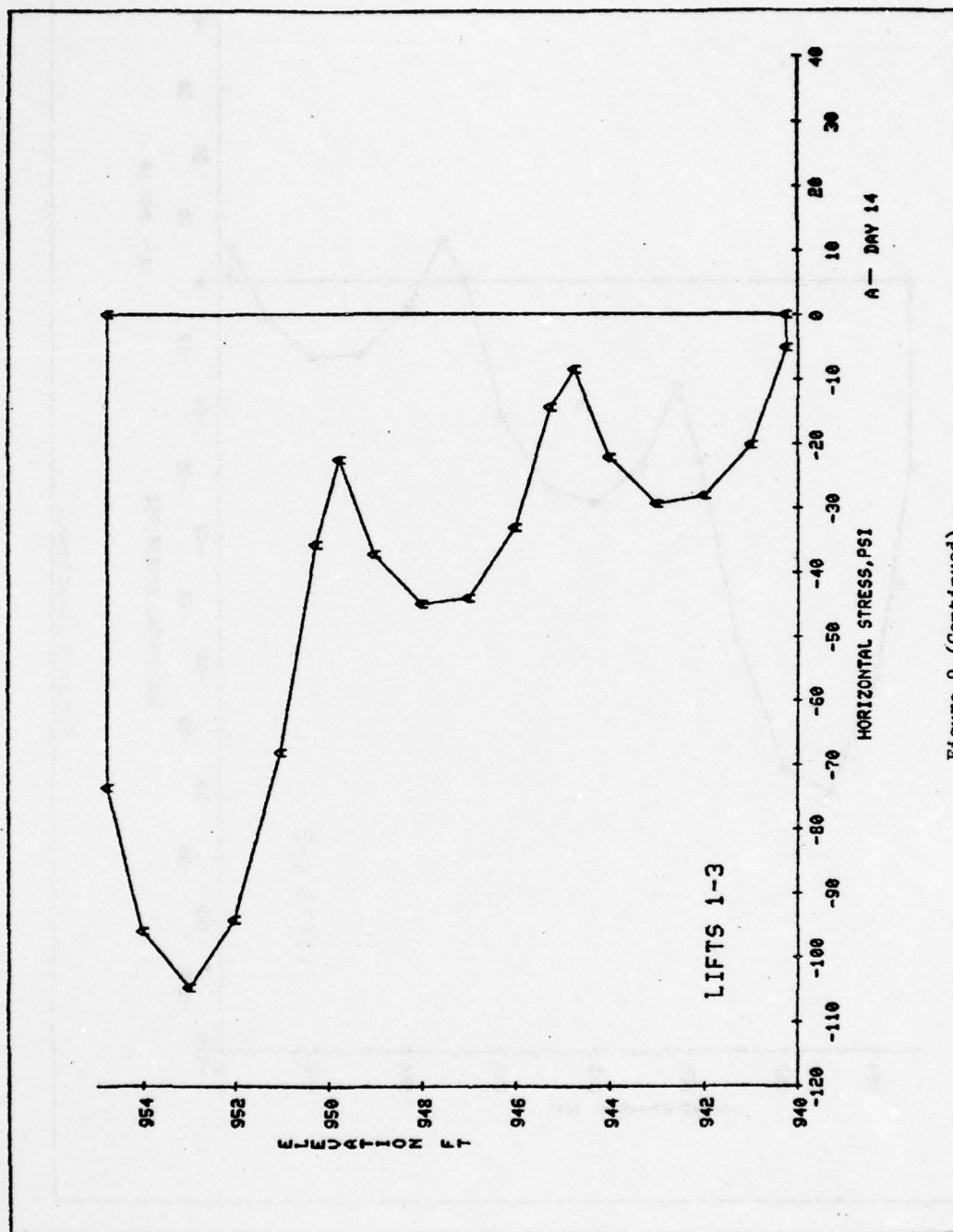


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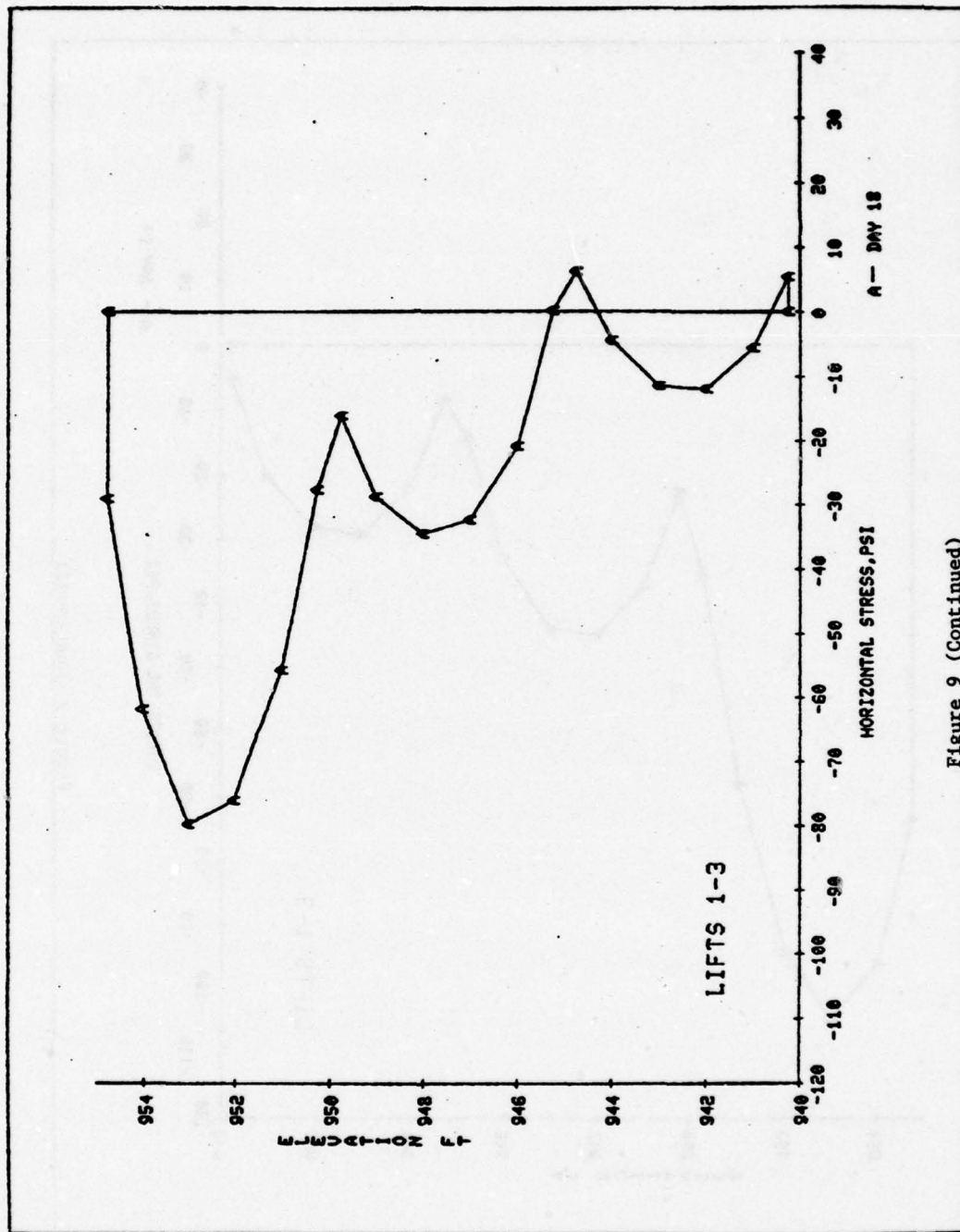


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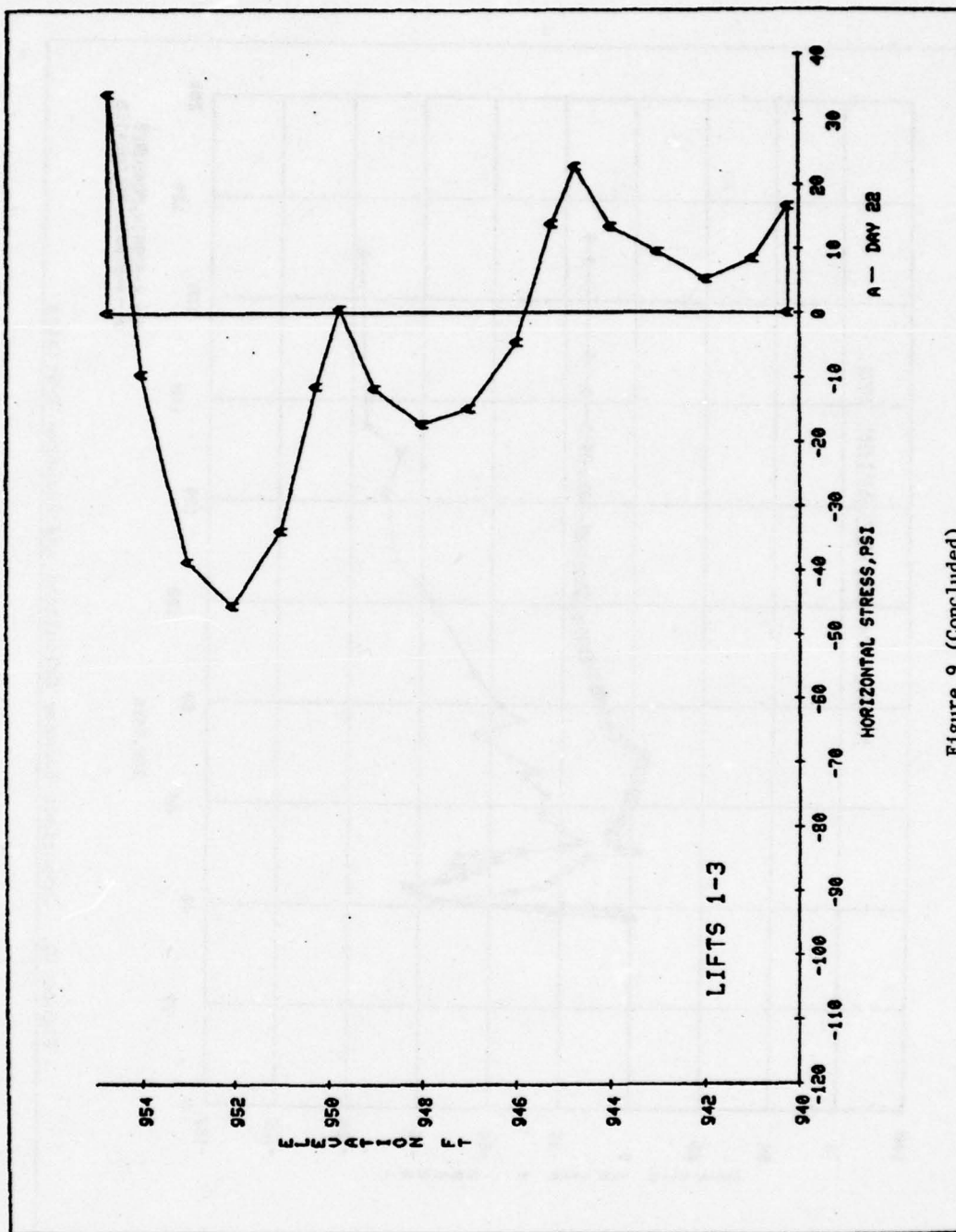


Figure 9 (Concluded)

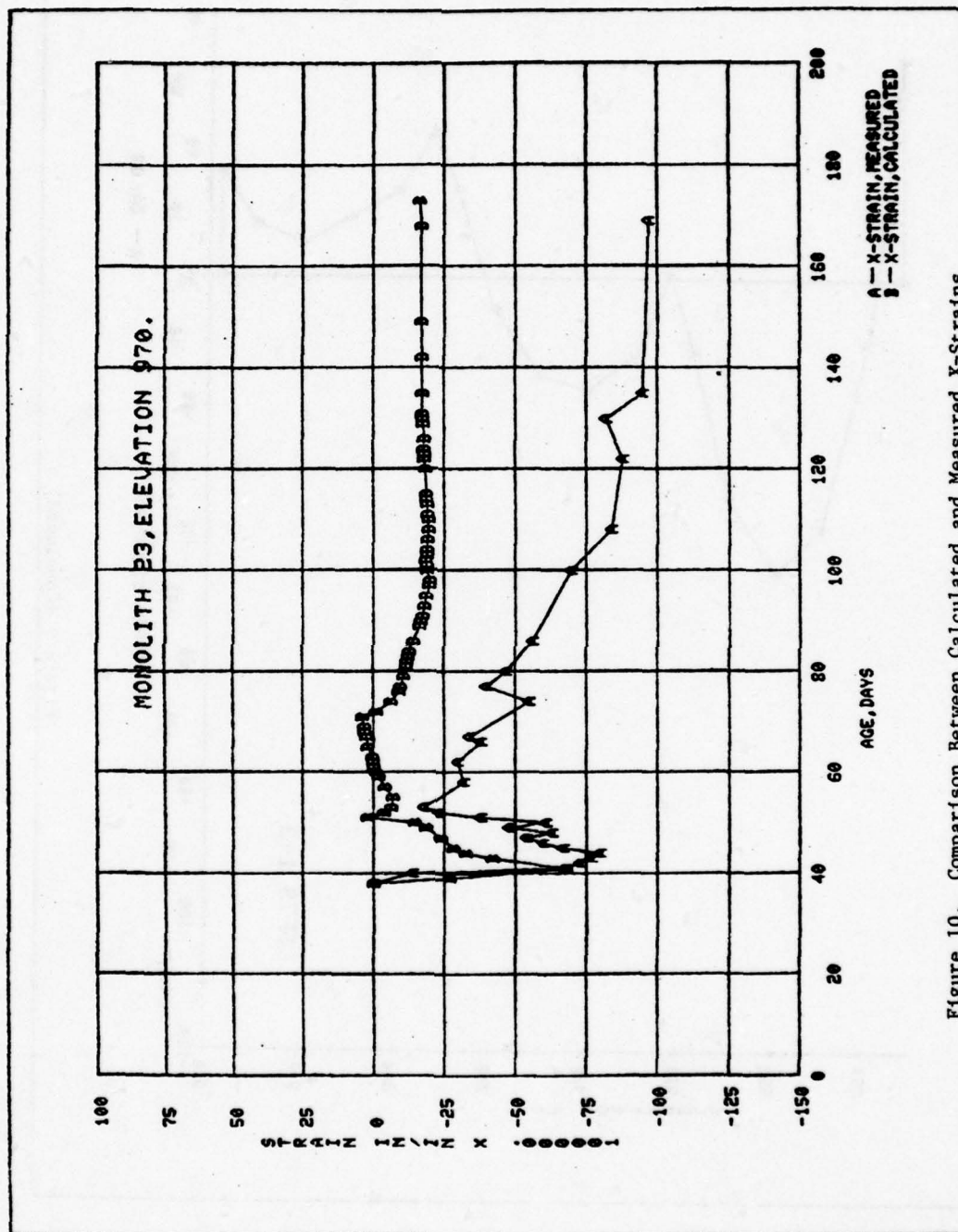


Figure 10. Comparison Between Calculated and Measured X-Strains

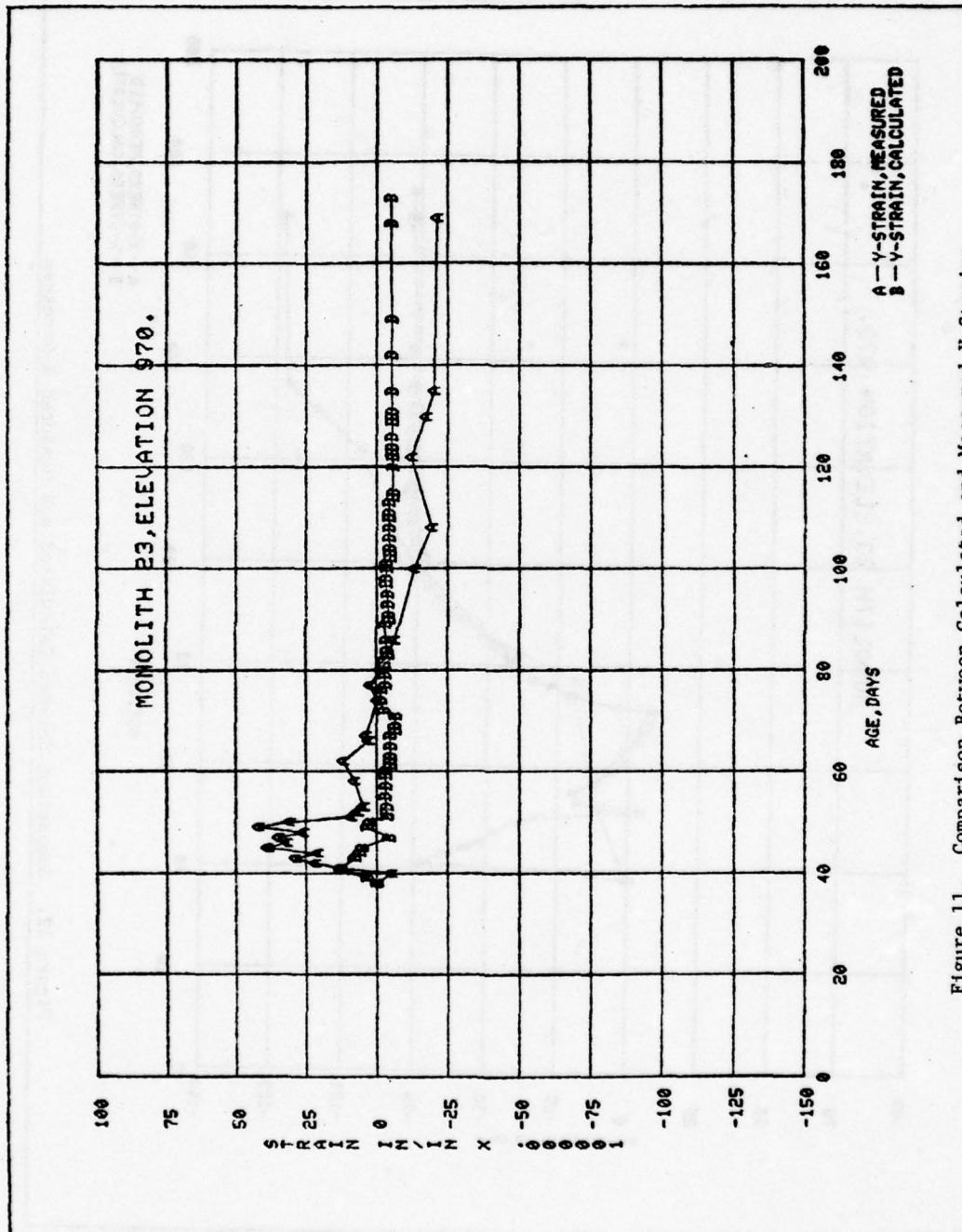


Figure 11. Comparison Between Calculated and Measured Y-Strains

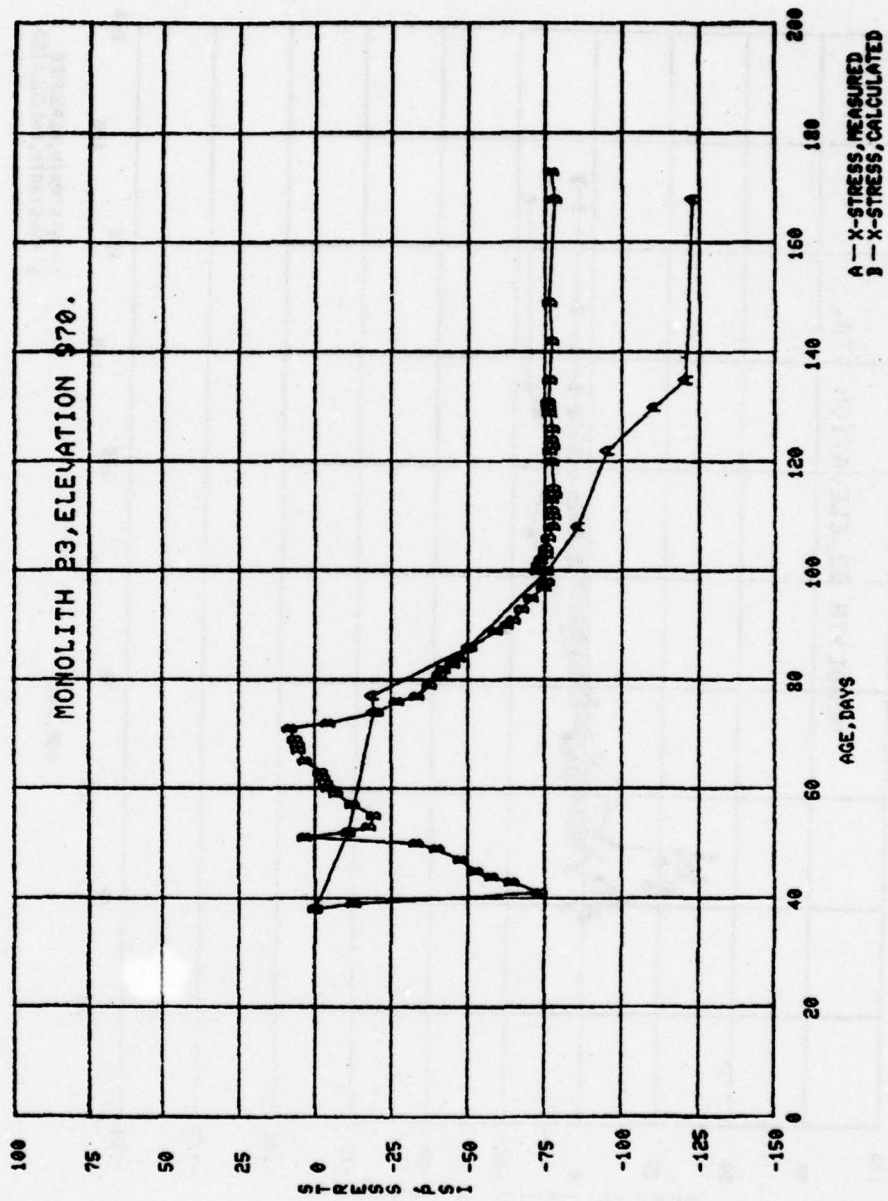


Figure 12. Comparison Between Calculated and Measured X-Stresses

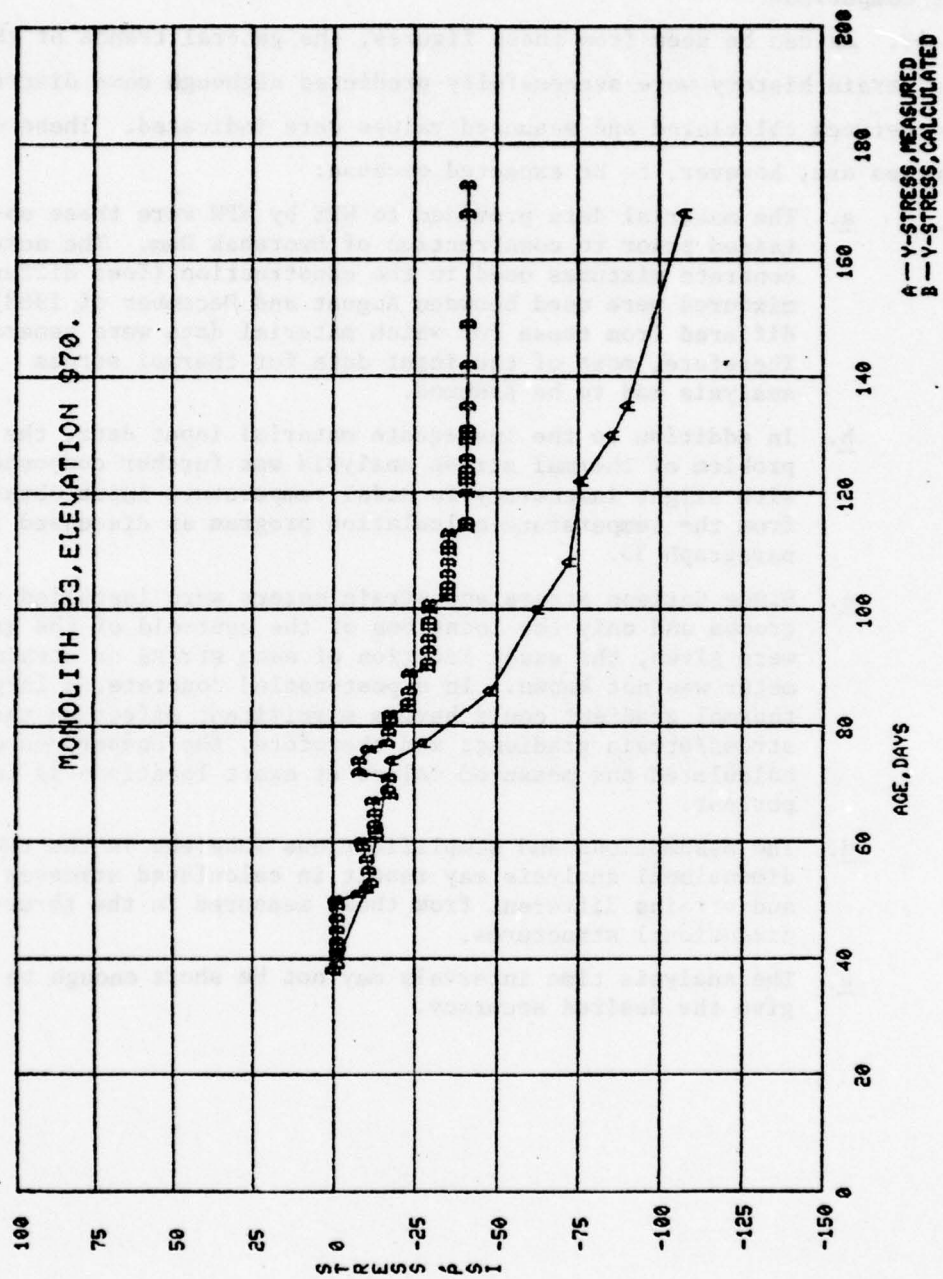


Figure 13. Comparison Between Calculated and Measured Y-Stresses

were several days after lift placement, these data were adjusted to match the calculated data at zero dates in order to obtain a more meaningful comparison.

43. As can be seen from these figures, the general trends of the stress/strain history were successfully predicted although some discrepancies between calculated and measured values were indicated. These discrepancies are, however, to be expected because:

- a. The material data provided to WES by NPW were those obtained prior to construction of Dworshak Dam. The actual concrete mixtures used in the construction (four different mixtures were used between August and December of 1968) differed from those for which material data were generated. Therefore, most of the input data for thermal stress analysis had to be assumed.
- b. In addition to the inadequate material input data, the problem of thermal stress analysis was further compounded with slight inaccuracy in nodal temperature input obtained from the temperature-calculation program as discussed in paragraph 33.
- c. Since Carlson stress and strain meters were installed in groups and only the locations of the centroid of the group were given, the exact location of each stress or strain meter was not known. In a post-cooled concrete, a large thermal gradient could have a significant effect on the stress/strain gradient; and therefore, the comparison of calculated and measured values at exact locations is important.
- d. The assumptions and simplifications inherent in the two-dimensional analysis may result in calculated stresses and strains different from those measured in the three-dimensional structures.
- e. The analysis time intervals may not be short enough to give the desired accuracy.

PART V: CONCLUSIONS AND RECOMMENDATIONS

44. Based on the results of this investigation, it can be concluded that the temperature and thermal stress calculation programs currently being used by the Corps are acceptable provided that complete thermal and material properties and environment data are available. This conclusion was drawn based upon the fact that the temperature and thermal stress analysis computer programs did successfully predict the trends of temperature and stress/strain history, respectively, although some discrepancies between calculated and measured values were noted.

45. Recommendations for further improvement of temperature and thermal stress/strain calculation programs are as follows.

- a. Further progress in temperature and thermal stress calculations for mass concrete structures is closely linked to the development of quantitative information on thermal, creep, and mechanical properties of concrete. The existing material data in the literature need to be analyzed and data storage and retrieval systems should be developed. The information on early age (e.g., zero through three days) thermal and mechanical properties is lacking at the current state of the art. Systematic tests to develop this information are recommended.
- b. Many advances have been made in the finite element techniques since the original development of the temperature and thermal stress calculation programs. It is recommended that these programs be updated to incorporate more efficient and accurate methodology, e.g., isoparametric elements, on-board band width minimizer, non-linear material properties, etc.
- c. The existing two-dimensional programs should be expanded to include thin-shell elements for simulating rigid steel forms. Axisymmetric analysis capability should also be added. Ultimately, three-dimensional finite element programs should be developed.
- d. The mathematical formulation of the creep mechanism used in the thermal stress analysis program was based on the McHenry equation.⁵ Unfortunately, the derivation of the creep constants for the McHenry equation involves very time-consuming numerical analysis procedures. A simplified mathematical expression suitable for use with the finite element technique needs to be developed.

- e. In the WES version of the thermal stress program, the stress-free temperature for an element is defined as the temperature at 8 hr after placement. A rational approach for determining stress-free temperatures needs to be developed.
- f. In the existing programs, all thermal, creep, and mechanical properties are assumed to be temperature-independent. In the case of high cement-content concrete placed in a large mass, concrete temperatures as high as 120°F can be expected, and in areas of cooling pipes, temperatures may be as low as 45°F. These extreme temperatures have significant effects on the rate of heat generation and other mechanical properties; therefore, temperature-dependent properties need to be considered in the programs.
- g. In the current temperature program, any changes in insulating properties and cooling pipes are to be handled in a new lift. Therefore, a dummy lift must be introduced whenever the insulating properties or cooling water temperature varied. Simplified methods of modeling these changes within a lift should be developed.
- h. In the creep analysis, the stress relaxation and creep determinations are carried out by a time increment sequence. It is necessary to establish a guidance for selecting optimum time intervals which are short enough to give desired accuracy but long enough to retain computational efficiency.
- i. Solar radiation may have a significant effect on concrete temperatures in certain locations and times. This effect needs to be incorporated in the temperature calculation program.

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5. McHenry, D., "A New Aspect of Creep in Concrete and Its Application to Design," Proceedings, American Society for Testing and Materials, Vol 43, 1943.
6. Pirtz, D., "Creep Characteristics of Mass Concrete for Dworshak Dam," Structural Engineering Laboratory Report No. 652, University of California, 1965.

Table 1
Summary of Material Types

<u>Lift</u>	<u>Date of Placement</u>	<u>Cement Content (sks/cu yd)</u>	<u>Fly Ash Content (% of cement wt)</u>	<u>Designated Material Type</u>
Foundation	26 Aug 68	--	--	1
1	27 Aug	3.25	30	2
2	31 Aug	3.25	30	2
3	4 Sep	3.25	30	2
4	17 Sep	3.25	35	3
5	23 Sep	3.25	35	3
6	3 Oct	3.25	35	3
7	15 Oct	3.25	35	3
8	25 Oct	3.50	30	4
9	1 Nov	3.50	30	4
10	10 Nov	3.50	30	4
11	16 Nov	3.50	30	4
12	23 Nov	3.25	30	2
13	5 Dec	3.00	30	5
14	17 Dec	3.00	30	5

Table 2
Thermal Properties

<u>Material Type</u>	<u>Specific Heat (Btu/lb-°F)</u>	<u>Thermal Conductivity (Btu/hr-in.-°F)</u>	<u>Density (lb/in.³)</u>
1	0.220	0.113	0.089
2	0.220	0.113	0.089
3	0.220	0.113	0.089
4	0.220	0.118	0.089
5	0.220	0.107	0.089

Table 3
Adiabatic Temperature Rise Input

Time (Day)	Temperature (°F)				
	Material Type 1	Material Type 2	Material Type 3	Material Type 4	Material Type 5
0.	0.	0.	0.	0.	0.
1.00	0.	9.4	8.8	10.4	8.4
2.00	0.	17.0	16.3	19.7	14.3
3.00	0.	20.7	19.9	22.4	19.0
4.00	0.	23.4	22.3	25.0	21.8
6.00	0.	26.4	25.2	27.8	25.0
7.00	0.	28.0	26.7	29.3	26.7
10.00	0.	31.4	29.7	32.9	29.9
14.00	0.	35.0	33.0	36.9	33.1
17.00	0.	37.0	34.9	39.1	34.9
21.00	0.	39.0	36.9	41.4	36.6
25.00	0.	40.8	38.7	43.5	38.1
28.00	0.	41.4	39.5	44.0	38.8
60.00	0.	49.0	46.6	51.4	45.7
90.00	0.	52.8	50.3	55.4	49.5
180.00	0.	59.5	56.8	62.2	55.8

Table 4
Cooling Water Removal Schedule

<u>Day</u>	<u>Lift</u>
22	1
26	2
30	3
43	4
49	5
59	6
71	7
81	8
88	9
97	10
103	11
110	12
122	13
123	14

Table 5
Thermal Conductivity of Insulation Material

<u>Lift</u>	<u>Top Eleva- tion (ft)</u>	<u>Conductivity (Btu/hr-in.-°F)</u>
Foundation	940	--
1	945	--
2	950	--
3	955	--
4	960	0.003
5	965	0.003
6	970	0.003
7	975	0.003
8	980	0.002
9	985	0.002
10	990	0.002
11	995	0.002
12	1000	0.002
13	1005	0.002
14	1010	0.002

Table 6
Average Wind Velocity and Its Corresponding
Convection Transfer Coefficient

<u>Lift</u>	<u>Average Wind Velocity (fps)</u>	<u>Convection Transfer Coefficient (Btu/hr-in.²-°F)</u>
Foundation	4.4	0.013
1	4.4	0.013
2	4.4	0.013
3	2.9	0.011
4	1.5	0.009
5	1.5	0.009
6	2.9	0.011
7	4.4	0.013
8	2.9	0.011
9	5.9	0.015
10	4.4	0.013
11	5.9	0.015
12	5.9	0.015
13	2.9	0.011
14	4.4	0.013

Table 7
Heat Transfer Coefficient

<u>Lift</u>	<u>Heat Transfer Coefficient</u> <u>(Btu/hr-in.²-°F)</u>
Foundation	0.0133
1	0.0133
2	0.0133
3	0.0111
4	0.0023
5	0.0023
6	0.0024
7	0.0024
8	0.0017
9	0.0018
10	0.0017
11	0.0018
12	0.0018
13	0.0017
14	0.0017

Table 8
Mechanical Input Properties - Material Type 1

<u>Time (day)</u>	<u>Modulus of Elasticity (psi)</u>	<u>Poisson's Ratio</u>	<u>Coefficient of Thermal Expansion (in./°F)</u>
0	2.8×10^6	0.20	5.5×10^{-6}
200	2.8×10^6	0.20	5.5×10^{-6}

Table 9
Mechanical Input Properties - Material Type 2

<u>Time</u> <u>(day)</u>	<u>Modulus</u> <u>of</u> <u>Elasticity</u> <u>(10⁶ x psi)</u>	<u>Poisson's</u> <u>Ratio</u>	<u>Coefficient of</u> <u>Thermal Expansion</u> <u>(10⁻⁶ x in./°F)</u>
0	0	0	5.48
0.5	0.3	0.17	5.48
1.0	0.6	0.17	5.48
1.5	0.9	0.17	5.48
2.0	1.10	0.17	5.48
2.5	1.22	0.17	5.48
3.0	1.35	0.17	5.48
4.0	1.53	0.17	5.48
5.0	1.70	0.17	5.48
6.0	1.82	0.17	5.48
7.0	1.90	0.17	5.48
8.0	2.00	0.17	5.48
12.0	2.30	0.17	5.48
16.0	2.49	0.17	5.48
20.0	2.62	0.17	5.48
28.0	2.85	0.17	5.48
36.0	3.02	0.18	5.48
44.0	3.15	0.19	5.48
52.0	3.26	0.20	5.48
60.0	3.35	0.20	5.48
70.0	3.45	0.21	5.48
80.0	3.53	0.21	5.48
90.0	3.62	0.22	5.48
100.0	3.70	0.22	5.48
120.0	3.80	0.22	5.48
140.0	3.90	0.22	5.48
160.0	4.00	0.22	5.48
180.0	4.09	0.22	5.48
200.0	4.15	0.22	5.48

Table 10
Mechanical Properties Input - Material Type 3

<u>Time</u> <u>(day)</u>	<u>Modulus</u> <u>of</u> <u>Elasticity</u> <u>(10⁶ x psi)</u>	<u>Poisson's</u> <u>Ratio</u>	<u>Coefficient of</u> <u>Thermal Expansion</u> <u>(10⁶ x in./°F)</u>
0	0	0	5.48
0.5	0.25	0.17	5.48
1.0	0.55	0.17	5.48
1.5	0.85	0.17	5.48
2.0	1.05	0.17	5.48
2.5	1.17	0.17	5.48
3.0	1.30	0.17	5.48
4.0	1.48	0.17	5.48
5.0	1.65	0.17	5.48
6.0	1.77	0.17	5.48
7.0	1.85	0.17	5.48
8.0	1.95	0.17	5.48
12.0	2.25	0.17	5.48
16.0	2.44	0.17	5.48
20.0	2.57	0.17	5.48
28.0	2.80	0.17	5.48
36.0	2.97	0.18	5.48
44.0	3.10	0.19	5.48
52.0	3.21	0.20	5.48
60.0	3.30	0.20	5.48
70.0	3.40	0.21	5.48
80.0	3.48	0.21	5.48
90.0	3.57	0.22	5.48
100.0	3.65	0.22	5.48
120.0	3.75	0.22	5.48
140.0	3.85	0.22	5.48
160.0	3.95	0.22	5.48
180.0	4.40	0.22	5.48
200.0	4.10	0.22	5.48

Table 11
Mechanical Properties Input - Material Type 4

Time (day)	Modulus of Elasticity ($10^6 \times \text{psi}$)	Poisson's Ratio	Coefficient of Thermal Expansion ($10^6 \times \text{in./}^\circ\text{F}$)
0	0	0	5.50
0.5	0.4	0.17	5.50
1.0	0.8	0.17	5.50
1.5	1.1	0.17	5.50
2.0	1.3	0.17	5.50
2.5	1.45	0.17	5.50
3.0	1.58	0.17	5.50
4.0	1.75	0.17	5.50
5.0	1.90	0.17	5.50
6.0	2.03	0.17	5.50
7.0	2.14	0.17	5.50
8.0	2.22	0.17	5.50
12.0	2.50	0.17	5.50
16.0	2.70	0.17	5.50
20.0	2.83	0.17	5.50
28.0	3.06	0.17	5.50
36.0	3.22	0.18	5.50
44.0	3.35	0.19	5.50
52.0	3.48	0.20	5.50
60.0	3.58	0.20	5.50
70.0	3.66	0.21	5.50
80.0	3.75	0.21	5.50
90.0	3.82	0.22	5.50
100.0	3.90	0.22	5.50
120.0	4.00	0.22	5.50
140.0	4.10	0.22	5.50
160.0	4.20	0.22	5.50
180.0	4.30	0.22	5.50
200.0	4.35	0.22	5.50

Table 12
Mechanical Properties Input - Material Type 5

<u>Time (day)</u>	<u>Modulus of Elasticity (10⁶ x psi)</u>	<u>Poisson's Ratio</u>	<u>Coefficient of Thermal Expansion (10⁻⁶ x in./°F)</u>
0	0	0	5.40
0.5	0.2	0.17	5.40
1.0	0.4	0.17	5.40
1.5	0.7	0.17	5.40
2.0	0.9	0.17	5.40
2.5	1.03	0.17	5.40
3.0	1.16	0.17	5.40
4.0	1.35	0.17	5.40
5.0	1.50	0.17	5.40
6.0	1.62	0.17	5.40
7.0	1.72	0.17	5.40
8.0	1.80	0.17	5.40
12.0	2.10	0.17	5.40
16.0	2.30	0.17	5.40
20.0	2.42	0.17	5.40
28.0	2.68	0.17	5.40
36.0	2.81	0.18	5.40
44.0	2.95	0.19	5.40
52.0	3.07	0.20	5.40
60.0	3.16	0.20	5.40
70.0	3.27	0.21	5.40
80.0	3.33	0.21	5.40
90.0	3.42	0.22	5.40
100.0	3.50	0.22	5.40
120.0	3.60	0.22	5.40
140.0	3.70	0.22	5.40
160.0	3.80	0.22	5.40
180.0	3.90	0.22	5.40
200.0	3.95	0.22	5.40

Table 13
Constants for Creep Equation

<u>Time</u>	<u>a₁</u>	<u>a₂</u>
0	0.960 x 10 ⁻⁶	0.463 x 10 ⁻⁶
1	.920 x 10 ⁻⁶	.475 x 10 ⁻⁶
4	.545 x 10 ⁻⁶	.565 x 10 ⁻⁶
6	.405 x 10 ⁻⁶	.500 x 10 ⁻⁶
8	.353 x 10 ⁻⁶	.442 x 10 ⁻⁶
10	.318 x 10 ⁻⁶	.395 x 10 ⁻⁶
16	.250 x 10 ⁻⁶	.289 x 10 ⁻⁶
20	.219 x 10 ⁻⁶	.248 x 10 ⁻⁶
24	.191 x 10 ⁻⁶	.225 x 10 ⁻⁶
28	.170 x 10 ⁻⁶	.215 x 10 ⁻⁶
32	.147 x 10 ⁻⁶	.208 x 10 ⁻⁶
44	.105 x 10 ⁻⁶	.191 x 10 ⁻⁶
60	.690 x 10 ⁻⁷	.170 x 10 ⁻⁶
76	.440 x 10 ⁻⁷	.150 x 10 ⁻⁶
100	.220 x 10 ⁻⁷	.122 x 10 ⁻⁶
200	0.200 x 10 ⁻⁷	0.100 x 10 ⁻⁶

APPENDIX A: TWO-DIMENSIONAL TEMPERATURE CALCULATION PROGRAM (WES VERSION)

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S      IDEN?  BOCB46, B-DORSHK TEMP CALC 13 JUNE 1978      00000020
S      OPTION FORTRAN      00000030
S      FORTV  XREF, MAP, DECK      00000040
S      LIMITS  05, 35K, 13000      00000050
S      FILE    C*, XJS, 1L, NEW, TOBJFIL      00000060
C      PROGRAM NO 42 K5 G403      00000070
C      TEMPERATURE PROGRAM WITH PLOTTER OUTPUT OF EXTRA OUTPUT NODES      00000080
C      00000090
      PARAMETER MAXN=500, MAXBN=9, PXE=480      00000100
      COMMON NDAY, NUMEL, NCBH, NCPH, AUMHAT, ADT, INTER, ET, TIME, NUMNP, NUME,      00000110
1     NUMOC, PLTIME, B(MAXN), X(MAXN), Y(MAXN), T(MAXN), D(MAXN), TT(MAXN),      00000120
2     IX(MXE, 5), PLTH(MXE), VOL(MXE), HEC(16), LM(5), E(313), KX(4), S(5, 5),      00000130
3     RCOND(10), RPHY(10), DENS(10), QX(35, 2, 10), NSTRB(10), ET(100, 2, 3),      00000140
4     IC(210), JC(210), HC(210), TMC(210), CL(210), ISPEN, PLACET, NPLP,      00000150
5     IP(210), HP(210), TP(210), TYP(210), IETC(210), NE, TEMPMAX, PDAY,      00000160
6     PEAKDAY, NODEPEAK, PEAKTEMP, NPEAKNCE, TSF(MXE)      00000170
      COMMON /OUTPUT/ NNODE, MCOUNT, NNODE(30), LIFT(30), TITLE(16), IPUNCH,      00000180
1     BPLC(5), NPLOT, NDATE(2)      00000190
      COMMON /SYNARG/ NUMN, MBAND, A(MAXN, MAXBN), Q(MAXN)      00000200
      COMMON /CHANN/ MNPLOT      00000210
      COMMON /NPRIN/ NTAPE11      00000220
      WRITE(98, 700)      00000230
700  FORMAT(// " STRESS FREE ELEM. TEMP AT 6 HR AFT PLACEMENT" //)      00000240
      WRITE(99, 700)      00000250
C      00000260
      CALL DECK      00000270
      WRITE(6, 200) TEMPMAX, PDAY, NPEAKNCE      00000280
200  FORMAT(" *****PEAK TEMPERATURE",      00000290
1     " *****", //      00000300
2     " THE PEAK TEMPERATURE FOR THIS RUN IS ", F7.2, " OCCURS ON",      00000310
3     " THE ", E6.1, " DAY AT NODE NO. ", I4, // " *****",      00000320
4     " *****")      00000330
400  FORMAT(1X, 16A4)      00000340
      CALL TPLOT      00000350
      END FILE 11      00000360
      WRITE (06, 9090)      00000370
9090  FORMAT ('PROCESSING COMPLETE')      00000380
      STOP      00000390
      END      00000400
SUBROUTINE DECK      00000410
C      TRANSIENT TEMPERATURE ANALYSIS OF CONCRETE STRUCTURES      00000420
C      BY THE FINITE ELEMENT METHOD      00000430
C      00000440
C      00000450
C      PROGRAM NO 42 K5 G403      00000460
C      00000470
C      CORPS OF ENGINEERS      00000480
C      NORTH PACIFIC DIVISION      00000490
C      WELLS HALLA DISTRICT      00000500
C      00000510
C      PROGRAM BY DR EDWARD L WILSON UNIVERSITY OF CALIF. BERKELEY      00000520
C      ADAPTED TO IBM 360/50 BY GRANT ANDERSON      00000530
C      00000540

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C
PARAMETER MAXN=500,MAXBH=9,MXE=480
COMMON NODAY,NUMEL,NCBH,NCPT,NUMMAT,NDT,INTER,DT,TIME,NUMNP,NUME;
1 NUMQC,PLTIME,B(MAXN),X(MAXN),Y(MAXN),T(MAXN),D(MAXN),TT(MAXN),
2 IX(MXE),PLTH(MXE),VOL(MXE),KEC(16),LM(5),E(3,3),KX(4),S(5,5),
3 SCND(10),SPHT(10),DENS(10),QX(35,2,10),WSTOP(10),ET(100,2,3),
4 IC(210),JC(210),HC(210),TMC(210),CL(210),ISRAH,PLACET,NELP,
5 TP(210),HP(210),TP(210),TYP(210),JETC(210),NE,TEMPHAX,PDAV,
6 PMAKDAY,NONEPEAK,PEAKTEMP,PEAKNCE,TFF(MXE)
COMMON /OUTPUT/ NNODE,MCOUNT,AQCE(30),LIFT(30),TITLE(16),IPUNCH,
1 SOLC(3),NPLOT,NDATE(2)
COMMON /SYNARS/ NUMN,HBAND,A(MAXN,MAXBH),P(MAXN)
COMMON /CHANN/ NCHANN
COMMON /NPIN/ NTAPE11
DIMENSION IR(5),TR(5),XUN(35),YUN(35)
REWIND 11

C
NF=20
TEMPHAX=0.
C*****
C READ AND PRINT OF CONTROL INFORMATION
C*****
90 READ(NF,999)HED
READ(NF,1000)NUMNP,NUMEL,NUMMAT,NUMQC,NUMET1,NUMET2,
1 NUMET3,NNODE,TIME,[SPAN,ICARDS,IPUNCH,SOLE(1),SOLC(2),
2 SOLC(3),NPLOT,NCHANN
WRITE(17,999)HED
WRITE(100,999)HED
WRITE(109,999)HED
WRITE(17,1000)NUMNP,NUMEL,NUMMAT,NUMQC,NUMET1,NUMET2,
1 NUMET3,NNODE,TIME,[SPAN,ICARDS,IPUNCH,SOLE(1),
2 SOLC(2),SOLC(3),NPLOT,NCHANN
WRITE(6,2013)
90 WRITE(6,2000) HED,NUMNP,NUMEL,NUMMAT,NUMQC,NUMET1,NUMET2,
1 NUMET3
NODAY=0
C*****READ OUTPUT CONTROL=NOCARD,NELCARD,NTAPE11 IF EACH OR ANY
C ARE = 1, THEN CARDS ARE PUNCHED FOR NODES AND ELEMENTS, AND
C OUTPUT TAPE CREATED RESPECTIVELY, =0 NO ACTION TAKEN,
READ(NF,2400)NOCARD,NELCARD,NTAPE11,ISCALE
2400 FORMAT(4I5)
WRITE(17,2400)NOCARD,NELCARD,NTAPE11,ISCALE
C*****
C READ OR GENERATE NODAL POINT INFORMATION
C*****
WRITE(6,2001)
L=1
60 READ(NF,1001)N,NROWN,X(N),Y(N),TT(N),NUMEV,NUMEVT,MOD,
1 NLLIM
WRITE(17,1001)N,NROWN,X(N),Y(N),TT(N),NUMEV,NUMEVT,MOD,
1 NLLIM
IF(1/SCALE.EQ.0)GO TO 5000

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	X(N)*X(N)=12.	00001063
	Y(N)*Y(N)=12.	00001064
5000	FACX=0	00001020
	FACY=0	00001020
	DIFF=N-1	00001040
	IF(NUMEV.EQ.0)GO TO 61	00001050
	IF(NUMEV.TQ.0E.NROWN, AND, NUMEV.EQ.1)GO TO 62	00001060
	GO TO 61	00001070
62	XUN(NROWN)*X(N)	00001080
	YUN(NROWN)*Y(N)	00001090
61	IF(N-L)GT.80.70	00001100
65	WRITE (6,2029) N	00001160
	GO TO 60	00001170
70	IF(NUMEV.EQ.2)GO TO 63	00001180
	DX=(X(N)-X(L=1))/DIFF	00001190
	DY=(Y(N)-Y(L=1))/DIFF	00001190
	DT=(T(N)-T(L=1))/DIFF	00001190
75	IF(NUMEV.EQ.2)GO TO 64	00001180
	X(N)=X(N)-2)*DX	00001180
	Y(N)=Y(N)-2)*DY	00001190
	T(N)=T(N)-2)*DT	00001200
	GO TO 60	00001210
83	LL=2	00001220
84	X(L)=X(L)+XUN(LL)-XUN(LL-1)	00001230
	Y(L)=Y(L)+YUN(LL)-YUN(LL-1)	00001240
	T(L)=T(L)+DT	00001250
	LL=LL+1	00001260
	GO TO 60	00001270
390	L1=N+1	00001280
	IF(FACX.LE.0) FACX=1.0	00001290
	IF(FACY.LE.0) FACY=1.0	00001300
	WRITE (6,2090) MOD,NLIM,FACX,FACY	00001310
400	N=N+1	00001320
	N1=N-MOD	00001330
	N2=N1-MOD	00001340
	IF(N2.GT.0) AND, (N2.GT.0) GO TO 405	00001350
	WRITE (6,2130)	00001360
	CALL EXIT	00001370
405	X(N)=X(N1)+FACX*(X(N1)-X(N2))	00001380
	Y(N)=Y(N1)+FACY*(Y(N1)-Y(N2))	00001390
	T(N)=T(N1)+DT	00001400
	IF(N.NLIM) GO TO 400	00001410
	L=N	00001420
	MOD=0	00001430
80	WRITE(6,2002) (K,X(K),Y(K),T(K),K=L1,L)	00001440
	L=L+1	00001450
	L=L	00001460
	IF(MOD.GT.0) GO TO 390	00001470
	IF (N-L) TQ.80.75	00001480
90	IF (NUMNP+1-L) 100,100,60	00001490
100	CONTINUE	00001500
	IF(SPE11.EQ.0)GO TO 3000	00001510

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WRITE(11)(N,X(N),Y(N),N=1,NLMNP)	00001520
3000 IF(NOSARD.EQ.0)GO TO 2410	00001520
PUNCH 2500.(N,X(N),Y(N),TY(K),N=1,NUMNP)	00001540
2500 FORMAT(15,5X13F10.3)	00001500
C.....	00001560
C READ AND PRINT OF ELEMENT PROPERTIES	00001570
C.....	00001580
2410 WRITE(6,2003)	00001590
N=0	00001600
103 READ(NF,1002) M,(IX(M,I),I=1,5),PLTH(M),MOD,NLIMIT,MPLTH,PLTINC	00001610
WRITE(7,1002)M,(IX(M,I),I=1,5),PLTH(M),MOD,NLIMIT,MPLTH,	00001620
1 PLTINC	00001620
IF (MOD .NE. 0) WRITE(6,2005) MOD,NLIMIT,MPLTH,PLTINC	00001640
104 N=N+1	00001650
IF (M-N) 107,107,105	00001660
105 IX(N,1)=IX(N-1,1)+1	00001670
IX(N,2)=IX(N-1,2)+1	00001680
IX(N,3)=IX(N-1,3)+1	00001690
IX(N,4)=IX(N-1,4)+1	00001700
IX(N,5)=IX(N-1,5)	00001710
PLTH(N)=PLTH(N-1)	00001720
GO TO 107	00001730
106 IF(N.EQ.NLIMIT) GO TO 108	00001740
N=N+1	00001750
N1=N-MOD	00001760
N2=N1-MOD	00001770
IF(N1.GT.0).AND.(N2.GT.0)) GO TO 1107	00001780
WRITE (6,2130)	00001790
CALL EXIT	00001800
1107 DO 2107 I=1,4	00001810
2107 IX(N,I)=2*IX(N1,I)-IX(N2,I)	00001820
IX(N,5)=IX(N1,5)	00001830
107 WRITE (6,2004) N,(IX(N,I),I=1,5),PLTH(N)	00001840
IF(MOD.EQ.0) GO TO 6107	00001850
IF(M.NE.N) GO TO 106	00001860
I=N-1	00001870
K=NLIMIT-MPLTH	00001880
DO 3107 I=1,K,MPLTH	00001890
L=1	00001900
DO 4107 J=1,MPLTH	00001910
L=L+1	00001920
4107 PLTH(L+1)=PLTH(L)	00001930
3107 PLTH(L+1)=PLTH(L+1)+PLTINC	00001940
GO TO 106	00001950
6107 IF(M-N) 108,108,104	00001960
108 IF (NUMEL-N) 109,109,103	00001970
109 CONTINUE	00001980
DO 110 I=1,NUMEL	00001990
110 PLTH(I)=PLTH(I)*24,	00002000
C	00002010
DO 115 N=1,150	00002020
TMC(N)=0.0	00002030

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119 TIME(N)*0.0                                00002040
    S1Q2#0,                                     00002050
    S1Q3#0,                                     00002060
    IF NTA#E12.EQ.0) GO TO 3010                00002070
    WRITE(11)IN,IX(M,I),I=1,5),S1Q1,S1Q2,S1Q3,NUMEL) 00002080
3010 IF NBLGARD.EQ.0) GO TO 2450                00002090
    PRNCH 2510,(M,IX(M,I),I=1,5),NUMEL)        00002100
2510 FORMAT(619)                                00002110
3030 RETURN                                     00002120
C.....                                         00002130
C READ AND PRINT MATERIAL PROPERTIES AND ENVIRONMENT TEMP 00002140
C.....                                         00002150
2450 IF NGBARD.EQ.1) GO TO 3030                00002160
    DO 120 N=1,NUMMAY                           00002170
    READ(NF,1050)MT,XCOND(MT),SFMT(MT),DENS(MT),HSTOP(MT) 00002180
    WRITE(7,1050)MT,XCOND(MT),SFMT(MT),DENS(MT),HSTOP(MT) 00002190
    WRITE(6,2018) MT                             00002200
    WRITE(6,2006) MT,XCOND(MT),SFMT(MT),DENS(MT),HSTOP(MT) 00002210
    HSTOP(MT),HSTOP(MT)*24,                      00002220
    WRITE(6,2007)                                00002230
    READ(NF,1008) ((QX(I,J,MT),J=1,2),I=1,NUMHQ) 00002240
    WRITE(6,2008) ((QX(I,J,MT),J=1,2),I=1,NUMHQ) 00002250
    WRITE(2,1008) ((QX(I,J,MT),J=1,2),I=1,NUMHQ) 00002260
    DO 120 I=1,NUMHQ                             00002270
    QX(I,1,MT)=QX(I,1,MT)*24,                   00002280
120 CONTINUE                                     00002290
    IF (NUMET1.EQ.0) GO TO 121                  00002300
    IET=1                                         00002310
    READ(NF,1008) ((ET(I,J,1),J=1,2),I=1,NUMET1) 00002320
    WRITE(7,1008) ((ET(I,J,1),J=1,2),I=1,NUMET1) 00002330
    WRITE(6,2012) IET,((ET(I,J,1),J=1,2),I=1,NUMET1) 00002340
    DO 1120 I=1,NUMET1                          00002350
    ET(I,1,1)=ET(I,1,1)*24,                     00002360
1120 ET(I,1,1)=ET(I,1,1)*24,                   00002370
    121 IF (NUMET2.EQ.0) GO TO 122              00002380
    IET=2                                         00002390
    READ(NF,1008) ((ET(I,J,2),J=1,2),I=1,NUMET2) 00002400
    WRITE(7,1008) ((ET(I,J,2),J=1,2),I=1,NUMET2) 00002410
    WRITE(6,2012) IET,((ET(I,J,2),J=1,2),I=1,NUMET2) 00002420
    DO 1121 I=1,NUMET2                          00002430
    ET(I,1,2)=ET(I,1,2)*24,                     00002440
1121 ET(I,1,2)=ET(I,1,2)*24,                   00002450
    122 IF (NUMET3.EQ.0) GO TO 123              00002460
    IET=3                                         00002470
    READ(NF,1008) ((ET(I,J,3),J=1,2),I=1,NUMET3) 00002480
    WRITE(7,1008) ((ET(I,J,3),J=1,2),I=1,NUMET3) 00002490
    WRITE(6,2012) IET,((ET(I,J,3),J=1,2),I=1,NUMET3) 00002500
    DO 123 I=1,NUMET3                          00002510
    ET(I,1,3)=ET(I,1,3)*24,                     00002520
123 ET(I,1,3)=ET(I,1,3)*24,                   00002530
C FOR EACH INTERVAL OF TIME--SEVERAL TIME STEPS 00002540
C.....                                         00002550
125 CONTINUE                                     00002560
    NCBH#0                                       00002570

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```

NCHMO
730E9TIME=24.
MCOUNT=0
DO 130 N=1,NUMNP
130 T(N)=0
IF (ICARD=NO.0) GO TO 130
KCARD = ICARD/5
KZ = ICARD - KCARD*5
IF (KZ .NE. 0) KCARD=KCARD+1
KC = 5
DO 135 I=1,KCARD
IF (I.EQ. KCARD) .AND. (KZ .NE. 0) KC=KZ
READ (NF,1035) (I(N),TR(N),N=1,KC)
WRITE (7,1035) (I(N),TR(N),N=1,KC)
DO 130 J=1,5
K = I(J)
T(K) = TR(J)
135 CONTINUE
1035 FORMAT (5(15F10.5))
130 IF (NMODE .EQ. 0) GO TO 149
READ (NF,1010) (NODE(I),I=1,NNODE)
WRITE (7,1010) (NODE(I),I=1,NNODE)
READ (NF,1010) (LIFT(I),I=1,NNODE)
WRITE (7,1010) (LIFT(I),I=1,NNODE)
WRITE (6,1030) (NODE(I),I=1,NNODE)
WRITE (6,1031) (LIFT(I),I=1,NNODE)
IF (IPUNCH .NE. 0) WRITE (6,2035) IPUNCH
IPUNCH = IPUNCH + 24
C
C
C READ AND PRINT OF LAYER PROPERTIES
149 ISPAN = ISPAN+1
150 READ (NF,999,END=997) TITLE
WRITE (7,999) TITLE
READ (NF,1004) NUMN,NUME,NUMCB,NUMCPI,INT,DT,PLTIME,PLACET
WRITE (7,1004) NUMN,NUME,NUMCB,NUMCPI,INT,DT,PLTIME,PLACET
C
IF (NUMN.EQ.0) GO TO 151
IF (NPLT.NE.0) STOP
RETURN
151 CONTINUE
WRITE (6,2032) ISPAN,TITLE
WRITE (6,2005) NUMN,NUME,NUMCB,NUMCPI,INT,DT,PLTIME,PLACET
PLTIME=PLTIME+24.
IF (ISPAN.EQ.1) NPLT=1
C
C
C ELIMINATE ALL INSULATING ELEMENTS AND COOLING PIPES WITH REMOVAL
TIME LESS THAN PLACEMENT TIME AND READ ADDITIONAL ONES
KN=0
DO 155 N=1,NCBH
IF (THC(N).LE. PLTIME) GO TO 155

```


KK=KK+1	00003070
IG(KK)=IG(N)	00003080
JG(KK)=JC(N)	00003090
HC(KK)=HC(N)	00003100
THC(KK)=THC(N)	00003110
CL(KK)=CL(N)	00003120
ETC(KK)=ETC(N)	00003130
155 CONTINUE	00003140
NCBL=KK+1	00003150
NCBH=KK+NUMCB	00003160
IF NUMCB.EQ.0) GO TO 160	00003170
N=NCBL	00003180
156 READ(1F,1005) IC(N),JC(N),HC(N),THC(N),ETC(N),IGEN	00003190
WRITE(1Z,1005) IC(N),JC(N),HC(N),THC(N),ETC(N),IGEN	00003200
IF IGEN.EQ.0) GO TO 158	00003210
JJ=(JC(N)-IC(N))/1	00003220
JC(N)=IC(N)+1	00003230
DO 157 I=1,JJ	00003240
IC(N+1)=IG(N)+1	00003250
JC(N+1)=JC(N)+1	00003260
HC(N+1)=HC(N)	00003270
THC(N+1)=THC(N)	00003280
ETC(N+1)=ETC(N)	00003290
157 N=N+1	00003300
158 N=N+1	00003310
IF N.LE.NCBH) GO TO 156	00003320
WRITE(6,2013) (IC(N),JC(N),HC(N),THC(N),ETC(N),N,NB1,NCBH)	00003330
DO 159 N=NCBL,NCBH	00003340
159 THC(N)=THC(N)+24	00003350
160 KK=0	00003360
DO 165 N=1,NCPH	00003370
IF (THP(N)/LE.PLTIME) GO TO 165	00003380
KK=KK+1	00003390
IP(KK)=IP(N)	00003400
HP(KK)=HP(N)	00003410
TP(KK)=TP(N)	00003420
THP(KK)=THP(N)	00003430
165 CONTINUE	00003440
NCBL=KK+1	00003450
NCPH=KK+NUMCP	00003460
IF NUMCP.EQ.0) GO TO 170	00003470
N=NCBL	00003480
166 READ(1F,1006) IP(N),HP(N),TP(N),THP(N),J,ISC	00003490
WRITE(1Z,1006) IP(N),HP(N),TP(N),THP(N),J,ISC	00003500
N=N+1	00003510
IF N.GT.NCPH) GO TO 168	00003520
IF INC.EQ.0) GO TO 166	00003530
167 IP(N)=IP(N-1)+INC	00003540
HP(N)=HP(N-1)	00003550
TP(N)=TP(N-1)	00003560
THP(N)=THP(N-1)	00003570
N=N+1	00003580

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	IF(IPL(N-1),LT,J) GO TO 167	00003590
	IF(N+LE,NCRH) GO TO 166	00003600
166	WRITE(6,8014) (IPL(N),HP(N),TP(N),TMP(N),N,N=NCPH,NCPH)	00003610
	DO 169 N=NCPH,NCPH	00003620
169	TMP(N)=THR(N)+24.	00003630
C		00003640
C	CHECK INCONSISTENCY OF LIFT INFORMATION AND REMOVAL OF INSULATING	00003650
C	ELEMENTS AND/OR COOLING PIPES	00003660
C		00003670
170	KK=0	00003680
	YY=DTN*FLOAT(NDT)	00003690
	IF(NCBH.EQ.0) GO TO 201	00003700
	DO 200 N=2,NCBH	00003710
	XH=THR(N)-PLTIME	00003720
	IF(XH.LT.YV) KK=1	00003730
200	CONTINUE	00003740
201	IF(NCRH.EQ.0) GO TO 208	00003750
	DO 205 N=1,NCPH	00003760
	XH=THR(N)-PLTIME	00003770
	IF(XH.LT.YV) KK=1	00003780
205	CONTINUE	00003790
208	IF(KK.NE.0) WRITE(6,2019)	00003800
C		00003810
C	SET ALL NEW NODES TO PLACEMENT TEMPERATURE AND CONTACT SURFACE AT	00003820
C	AVERAGE TEMPERATURES	00003830
C		00003840
	DO 210 I=1,NUMN	00003850
	B(I)=0.0	00003860
210	Q(I)=0.0	00003870
	DO 220 N=1,NUME	00003880
	IF(PLTM(N).GT,PLTIME) GO TO 220	00003890
	DO 225 I=1,4	00003900
	II=IX(N,I)	00003910
	IF(PLTM(N).EQ,PLTIME) B(II)=B(II)+PLACET	00003920
	IF(PLTM(N).LT,PLTIME) B(II)=B(II)+T(II)	00003930
225	Q(II)=Q(II)+1.0	00003940
220	CONTINUE	00003950
	DO 230 N=1,NUMN	00003960
	IF(Q(N).EQ.0.0) GO TO 230	00003970
	T(N)=B(N)/Q(N)	00003980
230	CONTINUE	00003990
C		00004000
	CALL LAYER	00004010
	IF(TEMPMAX.GT,PEAKTEMP) GO TO 2700	00004020
	TEMPMAX=PEAKTEMP	00004030
	PDAY=PEAKDAY	00004040
	NPEAKND=NODEPEAK	00004050
2700	GO TO 149	00004060
C		00004070
C	FORMAT STATEMENTS	00004080
C		00004090
997	WRITE(6,998)	00004092

```

999 FORMAT('END OF FILE')
STOP
999 FORMAT(16A4)
1000 FORMAT (8I5,F5.0,3I5,3F5.0,I2,I3)
1001 FORMAT(I15,I3,3F10.0,4I5)
1002 FORMAT(I15,3X,I4F10.0)
1003 FORMAT (6I5,E10.0,3I5,F5.0)
1004 FORMAT (12E,6F10.0)
1005 FORMAT(6I5,3F10.0)
1006 FORMAT(12I5,2F10.0,2I5)
1007 FORMAT(I15,3X,I3F10.0,2I5)
1008 FORMAT(2F10.0)
1010 FORMAT(16I5)
1030 FORMAT(1'NNODES FOR EXTRA OUTPUT'/(24I5))
1031 FORMAT(1' COLUMN HEADINGS FOR EXTRA OUTPUT'/(24I5))
2000 FORMAT ('G', 5X,16A4//25+NUMBER OF NODAL POINTS--,14/
1 25H NUMBER OF ELEMENTS----- 14 /25H NUMBER OF MATERIALS---g- 14/
2 25H NUMBER OF OB CARDS----- 14 /
3 125H BO OF EXT TEMP CARDS---- {4})
2001 FORMAT (10HO N,P, NO, 14X,14X,14X,14X,14X,14X,HTEMP)
2002 FORMAT (11IO,3E15.6)
2003 FORMAT (51HO N I J K L MATERIAL PLACEMENT TIME)
2004 FORMAT (5I5,11O,F16.4)
2005 FORMAT (1WO / 25HNUMBER OF NODAL POINTS-- 14/
1 25H NUMBER OF ELEMENTS----- 14 / 25H NUMBER OF CONVECTION BC-14/
2 25H NUMBER OF COOLING PIPE-- 14 / 25H NUMBER OF INCREMENTS--14/
3 25H OUTPUT INTERVAL----- 14 / 20M TIME INTERVAL----- F10.3/
4 25H BEGINNING TIME----- F8,2/25H PLACEMENT TEMPERATURE--
5 F8,2)
2006 FORMAT(16MO H,11X,4HCOND,11X,4HSPT,11X,4HDENS ,4X,20HTIME HEAT
1GENERATION STOPS/(16,3F15.6,F30.5))
2007 FORMAT(143NOADIABATIC TEMPERATURE RISE OF THE MATERIAL/ WHO TIME
1 9X,11HTEMPERATURE)
2008 FORMAT(F9.2,E15.6)
2009 FORMAT (4HO M 14X 1HK 14X 1HC 14X 1HD 14X 1HG, (14,4E15.6))
2011 FORMAT (27H17MO DIMENSIONAL PLANE BODY )
2012 FORMAT(127H8TEMPERATURE OF ENVIRONMENT,12 / 7HO TIME,4X,
1 11HTEMPERATURE/(F9.2,E15.6))
2013 FORMAT(12MOINSULATING ELEMENTS//4H 1,4H J,14X,1HW,41W TIME R
1REMOVED ENVIRON, ARRAY POSITION /(215,2F15.6,I5,I10))
2014 FORMAT(125HDETAILS OF COOLING PIPES//4H 1,14X,1HW,16H TEMPERA
1TUBE =3OW TIME REMOVED ARRAY POSITION/(115,3F15.6,I10))
2016 FORMAT(11WO,4X,13HMATERIAL TYPE -,13)
2019 FORMAT(139HO*** ERROR MESSAGE WARNING ONLY/IX,176HNEN LIFT DATA
1IS NOT SUPPLIED EVEN THOUGH A CHANGE WAS OCCURRED IN INSULATING/
2 /X,52HELEMENTS AND/OR COOLING PIPES, CALCULATION PROCEEDS)
2020 FORMAT (18HOCARD NO, 14, 33H CUT CF ORDER )
2021 FBMAT (13HOBAD CARD NO, 14)
2022 FBMAT 'ISPAN = ',15,16A4)
2035 FBMAT (19TEMPERATURES PURCHASE AT DAY =',15,1 FOR RESTART RUN')
2090 FBMAT(11W,6OX,5H MOD=,13,3X,6H NLIM=,14,3X,6H FACX=F10.5,
16H FACZ=F10.5)

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2895 FORMAT(1,1,60X,1 MOD=1,15,1 NLIMIT=1,15,1 MPLTH=1,15,1 PLTINC=1, 00004680
1F2221 000046810
2130 FORMAT(42H0INSUFFICIENT INFORMATION TO GENERATE MESH) 000046820
END 000046830
SUBROUTINE LAYER 000046840
PARAMETER MAXN=500,MAXBW=9,IXE=480 000046850
COMMON NODAY,NUMGL,NCBH,NCBH,NUMMAT,NDT,INTER,DT,TIME,NUMNP,NUME, 000046860
1 NUMGC,PLTIME,B(MAXN),X(MAXN),Y(MAXN),T(MAXN),D(MAXN),TT(MAXN), 000046870
2 IXHZE,5,PLTR(MXE),VOL(MXE),FEC(16),LM(5),E(3,3),KX(4),S(2,5), 000046880
3 SCND(19),SPHT(10),DENS(10),OX(35,2,10),VSTOR(10),ET(100,2,5), 000046890
4 IC(210),JC(210),HC(210),TFC(210),CL(210),ISRN,PLACET,NELP, 000046900
5 IP(250),WP(210),TP(210),TYP(210),IEXC(210),NE,TEMPHAX,PDAY, 000046910
6 PEAKDAY,NODEPEAK,PEAKTEMP,NPEAKNCE,TSF(MXE) 000046920
COMMON /OUTPUT/ NNODE,MCOUNT,NODE(30),LIFT(30),TITLE(16),IPUNCH, 000046930
1 SOLC(3),NPLOT,NDATE(2) 000046940
COMMON/SYMB/NUMN,MBAND,A(MAXN,MAXBW),Q(MAXN) 000046950
COMMON/NPRIV/NTAPE11 000046960
DIMENSION TNODE(30) 000046970
C 000046980
C.....000046990
C FROM CONDUCTIVITY MATRIX FOR COMPLETE BODY 000047000
C.....000047010
DO 130 I=1,NUMN 000047020
D(1)=0.0 000047030
B(1)=0.0 000047040
Q(1)=0.0 000047050
DO 130 J=1,MAXBW 000047060
130 A(1,J)=0.0 000047070
MBAND=0 000047080
ISTOP=0 000047090
C 000047100
DO 200 N=2,NUME 000047110
IF(PLV(N).GT.PLTIME) GO TO 200 000047120
MTYPE=IX(N,5) 000047130
COND=XCOND(MTYPE) 000047140
C 2, FROM ELEMENT CONDUCTIVITY MATRIX 000047150
C 000047160
DO 150 I=1,5 000047170
LM(1)=IX(N,1) 000047180
DO 150 J=1,5 000047190
150 S(1,J)=0.0 000047200
C 000050000
I=LM(1) 000050010
J=LM(2) 000050020
K=LM(3) 000050030
L=LM(4) 000050040
LM(5)=I 000050050
C 000050060
XG=(X(I)+X(J)+X(K)+X(L))/4, 000050070
YI=(Y(I)+Y(J)+Y(K)+Y(L))/4, 000050080
VOL(N)=0.0 000050090
C 000050100

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	DB 152 K=1,4	00005160
C	I=LH(K)	00005170
	J=LH(K+1)	00005180
	IF (I-J) 135,152,135	00005190
135	AJ=X(I)-X(J)	00005160
	AM=XX-X(I)	00005170
	BM=Y(I)-Y(J)	00005180
	BN=YY-X(I)	00005190
	C=BJ-BM	00005200
	DM=AK-AJ	00005210
C	XLAM=AJ+BM-AM+BJ	00005220
	IF (XLAM.GT.0) GO TO 136	00005230
	ISTOP=1	00005240
	WRITE(6,2003) N	00005250
136	VOL(N)=VOL(N)+XLAM*0.5	00005260
	CONM=2*COND/XLAM	00005270
C	E(1,1)=C+2+DX**2	00005280
	E(1,2)=BM+C-AM+DX	00005290
	E(1,3)=BJ+C+AJ+DX	00005300
	E(2,1)=E(1,2)	00005310
	E(2,2)=BM+2+AK**2	00005320
	E(2,3)=BJ+BM-AJ+AK	00005330
	E(3,1)=E(1,3)	00005340
	E(3,2)=E(2,3)	00005350
	E(3,3)=BJ+2+AJ**2	00005360
C	KH(1)=M	00005370
	KH(2)=M+1	00005380
	IF (K-4) 145,140,145	00005390
140	KH(2)=1	00005400
145	KH(3)=5	00005410
C	DB 153 I=1,3	00005420
	I=KH(I)	00005430
	DB 154 J=1,3	00005440
	J=KH(J)	00005450
151	S(I,I,JJ)=S(I,I,JJ)+E(I,J)*CONM	00005460
C	152 CONTINUE	00005470
C	DB 155 I=1,4	00005480
	DB 156 J=1,4	00005490
155	S(I,J)=S(I,J)+S(I,5)*S(J,5)/S(5,5)	00005500
C	3, ADD ELEMENT CONDUCTIVITY TO COMPLETE CONDUCTIVITY MATRIX	00005510
C	VOL(N)=VOL(N)+SPHT(MTYPE)*DENS(MTYPE)*0.25	00005520
C	DB 157 L=1,4	00005530
	I=LH(L)	00005540

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D(I)*D(I)+VOL(N)	00005630
DO 175 M=1,4	00005640
J=LH(M)-1+1	00005650
IF (MAXBW-J) 157,158,159	00005660
157 WRITE (6,2002) N	00005670
GO TO 200	00005680
159 IF (MBAND-J) 169,165,169	00005690
160 MBAND=J	00005700
165 IF (J) 175,175,170	00005710
170 A(I,J)=A(I,J)+S(L,M)	00005720
175 CONTINUE	00005730
C	00005740
200 CONTINUE	00005750
IF (ISTOP, EQ, 1) STOP	00005760
C.....	00005770
C BOUNDARY CONDITIONS	00005780
C.....	00005790
IF (NCPH, EQ, 0) GO TO 220	00005800
DO 215 N=1, NCPH	00005810
I=1C(N)	00005820
J=1C(N)	00005830
XL= SORT ((X(I)-X(J))*2+(Y(J)-Y(I))*2)	00005840
H=HC(N)*XL*0.25	00005850
A(I,1)=A(I,1)+H	00005860
A(J,1)=A(J,1)+H	00005870
K=J-1+1	00005880
IF (K) 212,212,210	00005890
210 A(I,K)=A(I,K)+H	00005900
GO TO 215	00005910
212 K=I-J+1	00005920
A(K,K)=A(K,K)+H	00005930
215 CLINT=XL	00005940
220 CONTINUE	00005950
C	00005960
C COOLING PIPES	00005970
C	00005980
IF (NCPH, EQ, 0) GO TO 225	00005990
DO 224 N=1, NCPH	00006000
I=1P(N)	00006010
A(I,1)=A(I,1)+HP(N)	00006020
224 B(I)=B(I)+HP(N)*TP(N)	00006030
225 CONTINUE	00006040
C	00006050
C 2* TEMPERATURE BOUNDARY CONDITIONS	00006060
C	00006070
DO 300 N=1, NUMN	00006080
C	00006090
IF (TT(N), EQ, 0.0) GO TO 308	00006100
DO 250 M=2, MBAND	00006110
K=N*M+1	00006120
IF (K) 235,235,230	00006130
230 B(K)=B(K)-A(K,M)*TT(N)	00006140

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A(N,M)=0.0	00006170
239 L=N*M-1	00006170
IF(NUMN-L) 245,240,240	00006170
240 B(L)=B(L)-A(N,M)*TT(N)	00006180
245 A(N,M)=0.0	00006190
250 CONTINUE	00006200
A(N,1)=1.0	00006210
TT(N)=TT(N)	00006220
300 CONTINUE	00006230
C	00006240
C.....	00006250
C SOLVE FOR NODAL JOINT TEMPERATURES	00006260
C.....	00006270
C FROM EFFECTIVE CONDUCTIVITY MATRIX FOR TANK ANNEALMENT	00006280
C	00006290
DT2=1.0/DT	00006300
DO 320 N=1,NUMN	00006310
IF(A(NP1)=0.0) A(N,1)=5.0	00006320
IF(TT(N).NE.0.0) GO TO 320	00006330
D(N)=DT2*D(N)	00006340
A(N,1)=A(N,1)+D(N)	00006350
320 CONTINUE	00006360
CALL SYMSOL(1)	00006370
C	00006380
C SET OR FLAGS FOR STRESS FREE TEMP OUTPUT	00006390
C	00006400
LL=0	00006410
NCPLG=1	00006420
NCYL=0	00006430
C	00006440
C IS THIS A FAKE LIFT, IE, FOR PIPE REMOVAL IN MIDCIFT?	00006450
C	00006460
IF(SNLP.GT.NUMN) GO TO 710	00006470
SFT=8?	00006480
KDT=SFT/DT	00006490
IF(DT.GT.SFT) GO TO 702	00006500
IF(DT.GE.0.5) GO TO 701	00006510
DDT=KDT	00006520
DDT1=SFT/DT	00006530
DEL=DDT1-DDT	00006540
IF(DEL.GE.0.5) GO TO 702	00006550
IF(DEL.EQ.0.0) GO TO 701	00006560
700 NCYL=KDT	00006570
NCPLG=2	00006580
GO TO 705	00006590
701 NCYL=KDT	00006600
NCPLG=1	00006610
GO TO 705	00006620
702 NCYL=KDT+1	00006630
NCPLG=2	00006640
705 CONTINUE	00006650
C	00006660

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C	CALC TEMP AT END OF EACH TIME INCREMENT	00006612
C	710 DB 000 KK=1,NDT	00006614
C	DETERMINATION OF HEAT GENERATION	00006620
C	DB 395 N=1,NUME	00006620
	IF(PLTM(N),GT,TIME) GO TO 395	00006620
	MTYPE=IX(N,5)	00006620
	TX=TIME-PLTM(N)	00006620
	IF(TX-GE,HSTOP(MTYPE)) GO TO 395	00006620
	DB 385 L=2,NUMHC	00006620
	XZ=QX(L,1,MTYPE)*TX	00006620
	IF(XZ-GE,0.0) GO TO 386	00006620
385	CONTINUE	00006620
386	DIEF=QX(L,1,MTYPE)-QX(L=1,1,MTYPE)	00006620
	GRAD=IQX(L,2,MTYPE)-QX(L=1,2,MTYPE)/DIEF	00006620
	QB=GRAD*VOL(N)	00006620
	DB 390 I=1,4	00006620
	IF(IX(N,1))	00006620
390	Q(1)=Q(1)+QB	00006620
395	CONTINUE	00006620
C	CONVECTION BOUNDARY CONDITION	00006620
C	IF(NECBH,0.0) GO TO 410	00006620
	DB 405 M=1,NECBH	00006620
	I=IC(M)	00006620
	J=JC(M)	00006620
	IF(IEVQ(M))	00006620
	DB 400 N=1,100	00006620
	IJ=N	00006620
	XZ=ET(N,1,IJ)-TIME	00006620
	IF(XZ) 400,400,401	00006620
400	CONTINUE	00006620
401	DIEF=ET(IJ,1,IJ)-ET(IJ-1,1,IJ)	00006620
	XZ=XZ/DIEF	00006620
	XXX=ET(IJ,2,IJ)-ET(IJ-1,2,IJ)	00006620
	TEMP=ET(IJ,2,IJ)-XXX * XYZ	00006620
	TEMP=TEMP*SOLC(IJ)	00006620
	XZ=HC(M)*CL(M)*TEMP*0.5	00006620
	Q(1)=Q(1)+XZ	00006620
405	Q(1)=Q(1)+XZ	00006620
410	CONTINUE	00006620
C	1/4 CALCULATE EFFECTIVE LOAD MATRIX	00006620
C	DB 450 I=1,NUMN	00006620
	Q(1)=Q(1)*B(I)*D(I)*T(I)	00006620
	IF(TT(I),NE,0.0) Q(1)=TT(I)	00006620
450	CONTINUE	00006620
C		00007110

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C	2+ SOLVE FOR TEMPERATURES	00007120
C		00007120
C	CALL SYMSQL(2)	00007120
C	DO 500 I=1,NUMN	00007120
	T(I)=0(I)	00007120
500	Q(I)=Q(I)	00007120
C		00007120
	TIME = TIME + DT	00007200
	DAY = TIME / 24.	00007200
	JJJ = TIME	00007220
C		00007220
C	PUNCH CARDS FOR RESTART RUN	00007220
C		00007220
	IF(JJJ,NE,IPUNCH) GO TO 530	00007220
	WRITE(87,2006) (I,T(I),I=1,NUMN)	00007220
	IF(NCPH.EQ,0) GO TO 502	00007220
	DO 501 N=1,NCPH	00007220
	XTMC = TMC(N)/24.0	00007300
501	WRITE(87,2002) IC(N),JC(N),HC(N),XTMC,ETC(N)	00007300
502	IF(NCPH.EQ,0) GO TO 510	00007320
	DO 503 N=1,NCPH	00007330
	XTMP = TMP(N)/24.0	00007330
503	WRITE(87,2008) IP(N),HP(N),TP(N),XTMP	00007330
2006	FORMAT (5(15,F10.5))	00007360
2007	FORMAT (2(15,F10.5),F10.2,15)	00007330
2008	FORMAT (15.5X,F10.5,F10.2,F10.2)	00007380
510	IF(NNODE.EQ,0) GO TO 554	00007390
	IF(MOD(DAY,1.0).NE,0.0) GO TO 554	00007400
	IF(NODE(1).GT,NUMN) GO TO 554	00007420
	KOUT=1	00007420
551	DO 552 I=1,NNODE	00007430
	TNODE(I) = 0.0	00007440
	I=NODE(I)	00007460
	IF(I,GT,NUMN) GO TO 800	00007460
	KOUT=1	00007470
552	TNODE(I) = T(I)	00007480
800	MCCOUNT = MCCOUNT + 1	00007490
	IF(MCCOUNT.GT,0) GO TO 553	00007500
	MCCOUNT = 40	00007510
	WRITE(16,3000) NDATE,HED,(LIFT(I),I=1,NNODE)	00007520
3000	FORMAT (1(1),2A4,9X,16A4,10 DAY IDEBT NUMBER(7X,2415))	00007530
553	WRITE(16,2030) DAY,(TNODE(I),I=1,KOUT)	00007540
	IF(NPLOT,NE,0) GO TO 554	00007550
	NODAY=NODAY+1	00007560
2030	FORMAT(F7.2,(24F5.1))	00007570
554	CONTINUE	00007580
	LL=LL+1	00007580
	IF(ISPAN.GT,1) GO TO 770	00007590
	IF(SK=NE.NDY) GO TO 755	00007590
	WRITE(88,780)	00007600
780	FORMAT("SPAN 1 VALUES-POSSIBLY FOUNDATION")	00007610

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770 IF (KX+NE.NCYL) GO TO 755                                00007620
DO 752 I=NELN,NUME                                           00007620
J1=IX(1,1)                                                    00007620
J2=IX(1,2)                                                    00007620
J3=IX(1,3)                                                    00007620
J4=IX(1,4)                                                    00007620
IF (J3+J4) GO TO 750                                         00007620
TSF(1)=(T(J1)+T(J2)+T(J3)+T(J4))/4.                         00007620
GO TO 751                                                      00007700
750 TSF(1)=(T(J1)+T(J2)+T(J3))/3,                             00007700
751 IF (NCFLG.EQ.1) GO TO 752                                00007720
TSF(1)=(TSF(1)+PLACET)*DT/NCYL*PLACET/(DT+NCYL)             00007720
752 CONTINUE                                                  00007740
WRITE(88,760) ISPAN,SPT,DT,DETI,PLACET,DAY,BCYL,KDT         00007740
760 FORMAT(1// " SPAN=-----",I4," SPT-HOURS=---",F10.3, / 00007760
1 " DT-HOURS=---",F10.3, / " SPT/DT=---",F10.3, /           00007720
2 " PLAC YEMP=",F10.3, / " DAYS=---",F10.3, /               00007700
3 " BCYL=---",I4, / " KDT-COUNTY=---",I4, / )                00007700
WRITE(88,761)(1,TSF(1),I=NELN,NUME)                         00007800
761 FORMAT(5(19,F10.3))                                        00007800
WRITE(89,767)(1,TSF(1),I=NELN,NUME)                         00007812
767 FORMAT(2X,18,F10.3)                                       00007813
755 CONTINUE                                                  00007819
IF (LL=INTER) 600,550,550                                     00007820
550 WRITE(16,2003) DAY,(N,T(N),N=1,NUMN)                    00007820
IF (N+NE12.EQ.0) GO TO 3820                                  00007850
WRITE(11,2004) DAY,(N,T(N),N=1,NUMN)                         00007860
3820 LL=0                                                      00007870
PEAKTEMP=0.                                                    00007900
DO 825 N=1,NUMN                                                00007910
IF (T(N).GT,PEAKTEMP) GO TO 826                               00007920
GO TO 825                                                      00007930
826 PEAKTEMP=T(N)                                              00007940
NDEPEAK=N                                                      00007950
PEAKDAY=DAY                                                      00007960
825 CONTINUE                                                  00007970
WRITE(16,2600) DAY,PEAKTEMP,NDEPEAK                          00007980
C                                                                00007990
600 CONTINUE                                                  00008000
NELP=NUME+1                                                    00008010
RETURN                                                         00008020
C*****                                                        00008030
C                                                                00008040
2001 FORMAT(1//8H TIME = ,F8.2,6H DAYS/(10(15,F8.2)))       00008050
2002 FORMAT (23H BAND TOO LARGE=EL,NO, 1H)                  00008060
2003 FORMAT(34H ZERO OR NEGATIVE AREA ELEMENT NO,15)        00008070
2004 FORMAT(8H TIME = ,F8.2,6H DAYS,100X,1H1/(1(16,F7.1),35X,1H1)) 00008080
2000 FORMAT(1//*****PEAK TEMPERATURE THIS CALCULATION,     00008090
1 "*****",1//3 THE PEAK TEMPERATURE FOR THE",E9.1," DAY ", 00008100
2 " ",F6.2," DEGREES AT NODE= ",I4)                          00008110
C                                                                00008120
END                                                            00008130

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	SUBROUTINE SYMSOL (KKK)	00008150
	PARAMETER MAXN=500,MAXMM=9,MAXE=400	00008155
C	COMMON /SYMARG/ NN,MM,A(MAXN,MAXMM),B(MAXN)	00008160
C	GO TO (1000,2000),KKK	00008170
C	REDUCE MATRIX	00008180
C		00008190
1000	DO 260 N=1,NN	00008200
	DO 260 L=2,MM	00008210
	C=A(N,L)/A(N,1)	00008220
	I=N+1	00008230
	IF(NN=1) 260,240,240	00008240
240	J=9	00008250
	DO 250 K=L,MM	00008260
	J=J+1	00008270
250	A(I,J)=A(I,J)-C*A(N,K)	00008280
260	A(N,L)=C	00008290
280	CONTINUE	00008300
	GO TO 500	00008310
C		00008320
C	REDUCE VECTOR	00008330
C		00008340
2000	DO 290 N=1,NN	00008350
	DO 290 L=2,MM	00008360
	I=N+1	00008370
	IF(NN=1) 290,285,285	00008380
285	B(I)=B(I)-A(N,L)*B(N)	00008390
290	B(N)=B(N)/A(N,1)	00008400
C	BACK SUBSTITUTION	00008410
C		00008420
	N=NN	00008430
300	N=N+1	00008440
	IF(N) 350,500,350	00008450
350	DO 400 K=2,MM	00008460
	L=N+K-1	00008470
	IF(NN=L) 370,370,370	00008480
370	B(N)=B(N)+A(N,K)*B(L)	00008490
400	CONTINUE	00008500
	GO TO 300	00008510
C		00008520
500	RETURN	00008530
C		00008540
	END	00008550
	SUBROUTINE TPLOT	00008560
	RETURN	00008570
	END	00008580
S	EXECUTE DUMP	00008590
S	LIMITS 40,33K,25000	00008600
S	FILE 07,D19,6L	00008610
S	FILE 08,D29,6L	00008620
		00008630
		00008640

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S	ERMFL	09,R/H,L,ROCC46/SFCUTDW1	00008650
	TAPES	11,A1D,.,.,DWORSH-WES#1	00008655
	HSG2	SAVE 11,BOMBICH,ROCC46,DWORSH-WES#1	00008656
S	DATA	20	00008660
S	BREAK		00008700
S	CONVER		00008710
S	LIMITS	10,2000	00008720
S	SYSOUT	0T	00008730
S	FILE	IN,D1R	00008740
S	BREAK		00008741
S	CONVER		00008742
S	LIMITS	10,3000	00008743
S	SYSOUT	0T	00008744
S	FILE	IN,D2R	00008750
S	ENDJOB		00008760

APPENDIX B: TWO-DIMENSIONAL THERMAL STRESS/STRAIN CALCULATION PROGRAM
(WES VERSION)

```

S IDENT ROCC46,CAMPBELL 000000020
S MSGJ 062878/1700 000000025
S OPTION FORTRAN 000000030
S FORTY XREF,MAP,DEGK 000000040
S LIMITS ,33K,,6000 000000050
S FILE C,X3S,1L,NEW,BSTBESDW 000000060
C STRESSV-WITH VARIABLE TIME AND STRAIN CAP INPUT 000000070
C***COPY AS OF 27 MARCH 77,INCL STRAIN,CAP,, SPECIFIC ANALYSIS TIMES 000000080
C ARBITRARY TWO-DIMENSIONAL STRESS STRUCTURE INCLUDING INCREMENTAL 000000090
C CONSTRUCTION, MC HENRY CREEP, RESIDUAL STRESSES, THERMAL STRESSBS, 000000100
C VARYING PRESSURE BOUNDARY CONDITIONS, AND BIMODULAR MATERIAL, 000000110
C PROPERTIES. 000000120
C 000000130
C MXN=MAXIMUM NO. OF NODES 000000140
C MXE=MAXIMUM NO. OF ELEMENTS 000000150
C MN2=MAX NODES * 2 000000160
C 000000170
C 000000180
C 000000190
C 000000200
C 000000210
C 000000220
C 000000230
C 000000240
C 000000250
C 000000260
C 000000270
C 000000280
C 000000290
C 000000300
C 000000310
C 000000320
C 000000330
C 000000340
C 000000350
C 000000360
C 000000370
C 000000380
C 000000390
C 000000400
C 000000410
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C 000000470
C 000000480
C 000000490
C 000000500
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C 000003100
C 000003110
C 000003120
C 000003130
C 000003140
C 000003150
C 000003160
C 000003170
C 000003180
C 000003190
C 000003200
C 000003210
C 000003220
C 000003230
C 000003240
C 000003250
C 00
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WRITE (6,2011) MTYPE,NUMTC,NCREEP(MTYPE),RO(MTYPE)      00000450
WRITE(6,2051)NSC      00000480
READ(NF,1005) ((E(I,J,MTYPE),J=1,6),I=1,NUMTC)      00000470
WRITE (6,2010) ((E(I,J,MTYPE),J=1,6),I=1,NUMTC)      00000460
DO 58 I=NUMTC,30      00000490
DO 58 J=1,6      00000500
58 E(I,J,MTYPE)=E(NUMTC+J,MTYPE)      00000510
IF(ISC.EQ.0)GO TO 910      00000520
READ(NF,1008)((SC(I,J,MTYPE),J=1,2),I=1,NSC)      00000530
WRITE(6,2052)((SC(I,J,MTYPE),J=1,2),I=1,NSC)      00000540
DO 75 I=NSC,30      00000550
DO 75 J=1,2      00000560
75 SC(I,J,MTYPE)=SC(NSC+J,MTYPE)      00000570
910 CONTINUE      00000580
IF (NCREEP(MTYPE)) 56,59,54      00000590
54 NCR=NCREEP(MTYPE)      00000600
READ(NF,1003) (TTT(I),(CIC(I,J,MTYPE),J=1,4),I=1,NCR)      00000610
WRITE (6,2013) MTYPE, (TTT(I),(CIC(I,J,MTYPE),J=1,4),I=1,NCR)      00000620
READ(NF,1005) (CC(I,MTYPE),I=1,4)      00000630
WRITE (6,2014) (CC(I,MTYPE),I=1,4)      00000640
59 CONTINUE      00000650
C****READ AND PRINT NODAL LOAD/DISPLACEMENT BOUNDARY COND***      00000652
WRITE(6,2004)      00000660
L=1      00000670
3006 READ(NF,3000)N,CODE(N),UR(N),UZ(N)      00000680
IF(N.EQ.1)GO TO 3006      00000690
3005 L=L+1      00000700
IF(N-L)3002,3001,3004      00000710
3004 CODE(L)=CODE(L-1)      00000720
UR(L)=0,      00000730
UZ(L)=0,      00000740
GO TO 3005      00000750
3002 WRITE(6,2017)N      00000760
CALL EXIT      00000770
3001 IF(L.EQ.NUMNP)GO TO 3008      00000780
GO TO 3006      00000790
C****READ NODAL POINT DATA FROM TAPE/DISK AND PRINT*****      00000791
3008 L=0      00000800
IF(READMODE.EQ.6)TAPE )GO TO 905      00000810
READ(NF,4000)(M,R(N),Z(N),N=1,NUMNP)      00000820
GO TO 906      00000830
905 READ(4)(M,R(N),Z(N),N=1,NUMNP)      00000840
906 CONTINUE      00000850
WRITE(6,2002)(K,CODE(K),R(K),Z(K),UR(K),UZ(K),K=1,NUMNP)      00000860
WRITE(3)(K,CODE(K),R(K),Z(K),UR(K),UZ(K),K=1,NUMNP)      00000870
WRITE (6,2001)      00000880
C****READ ELEMENT DATA FROM TAPE OR CARDS AND PRINT*****      00000881
N=0      00000890
IF(READMODE.EQ.6)TAPE )GO TO 908      00000900
READ(NF,4001)(M,(IX(N,I),I=1,5),(SIG(N,I),I=1,3),N=1,NUMEL)      00000910
GO TO 909      00000920
908 READ(4)(N,(IX(N,I),I=1,5),(SIG(N,I),I=1,3),N=1,NUMEL)      00000930

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909 CONTINUE
WRITE(6,2003)(N,(IX(N,I)-I=1,9),SIG(N,I),I=1,3),N=1,NUMEL)
WRITE(3)(N,(IX(N,I),I=1,9),SIG(N,I),I=1,3),N=1,NUMEL)
J=0
DO 340 N=1,NUMEL
DO 340 I=1,4
DO 325 L=1,4
KK=ABS(IX(N,I)-IX(N,L))
IF (KK-J) 325,325,320
320 J=KK
325 CONTINUE
340 CONTINUE
MBAND=2*J+2
NUMOL=0
NANAL=0
TIME=TI
TIM=TI
TLAST=TI
C*****READ ELEMENT STRESS FREE TEMPERATURES*****
L=1
3026 READ(NF,3020)M,TOLD(M)
IF (M.EQ.1)GO TO 3026
3025 L=L+1
IF (M-L)3022,3021,3024
3024 TOLD(L)=TOLD(L-1)
GO TO 3025
3022 WRITE(6,3027)M
CALL EXIT
3021 IF (L.EQ.NUMEL)GO TO 3031
GO TO 3026
3031 L=0
WRITE(6,3028)(M,TOLD(M),M=1,NUMEL)
DO 450 N=1,NUMEL
DE11(N)=0.
DE12(N)=0.
DE21(N)=0.
DE22(N)=0.
SIG(N,4)=0.
SIG(N,5)=0.
MTAG(N)=1
IF (SIG(N,1)) 445,445,440
440 IF (SIG(N,1)+SIG(N,2)) 441,441,442
441 MTAG(N)=2
GO TO 450
442 MTAG(N)=3
445 IF (SIG(N,2)) 450,450,448
448 MTAG(N)=4
450 CONTINUE
DO 460 N=1,NUMNP
FF(2*N-1)=0.
460 FF(2*N)=0.
C*****READ ANALYSIS TIMES(DAYS) FOR RUN

```

```

READ(INF,3017)(ANAL(N),N=1,NANAL)
WRITE(6,3042)(ANAL(N),N=1,NANAL)
3042 FORMAT(///" ANALYSIS TIMES FOR RUN(DAYS)"/,1X,18F7.1))
NAL=1
NCP=0
IF(NEXTRA.EQ.1)NCP=1
DO 870 KK=1,NUMMAT
IF(NCREEP(KK).GT.0)NCP=1
870 CONTINUE
890 DTT=1.0
NFLAG=0
NANAL=1
C*****READ LIFT CONTROL DATA*****
DO 600 LIL=1,NLAY
550 READ(INF,1006) LAY,NUMN,NUME(LAY),NUMPC,NP,NDT,TIMLA(LAY),TIMNL
WRITE(6,2008) LAY,NUMN,NUME(LAY),NUMPC,NP,NDT,TIMLA(LAY),TIMNL
NFLAG=0
NANAL=1
NUMNL=NUME(LAY)
IF(NFLAG.EQ.2)GO TO 951
897 IF(NNAL.EQ.NDT.AND.NCP.EQ.1)NFLAG=1
C*****READ NODAL TEMPERATURES FROM TAPE OR CARDS*****
951 IF(READMODE.EQ.6HTAPE)GO TO 901
READ(INF,3009)TIMETAPE
READ(INF,3007)(T(KK),KK=1,NUMN)
GO TO 902
901 READ(4,3040)TIMETAPE
READ(4,3041)(T(KK),KK=1,NUMN)
902 CONTINUE
IF(NANAL.GT.1)GO TO 940
IF(TIME-ANAL(NAL))943,944,943
944 DT=TIME-0.0
IF(TIMETAPE-TIME)941,952,941
940 IF(NFLAG.EQ.2)GO TO 947
IF(TIMETAPE-TIME)951,952,953
947 IF(TIMETAPE-TIME)951,952,953
952 DO 871 KK=1,NUMNL
I=IX(KK,1)
J=IX(KK,2)
K=IX(KK,3)
L=IX(KK,4)
IF(K.EQ.L)GO TO 872
TEMPE(KK)=(T(I)+T(J)+T(K)+T(L))/4.
GO TO 871
872 TEMPE(KK)=(T(I)+T(J)+T(K))/3.
871 CONTINUE
IF(NFLAG.NE.2)GO TO 895
DO 874 KK=1,NUMNL
874 TSAVE(KK)=TEMPE(KK)
895 IF(NCP.NE.1)GO TO 955
975 DDT1=ANAL(NAL+1)-ANAL(NAL)
IF(NFLAG.EQ.0)GO TO 896

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GO TO (960,985,964,981,963),NFLAG
961 DO 884 KK=1,NUMNL
884 TEMPE(KK)=TSAVE(KK)
896 IF (DDT1.GE.1.0.AND.DDT1.LT.2) DTT=0.5
IF (DDT1.GE.2.) DTT=1.0
GO TO 962
985 NEW=NUME(LAY-1)
DO 880 KK=1,NEW
880 TEMPE(KK)=(TSAVE(KK)+TOLD(KK))*SFTIM/24.+TOLD(KK)
DO 881 KK=NEW+1,NUMNL
881 TEMPE(KK)=TOLD(KK)
GO TO 966
964 DO 883 KK=1,NUMNL
883 TEMPE(KK)=(TSAVE(KK)+TOLD(KK))*SFTIM/24.+TOLD(KK)
960 DTT=SFTIM*.5/24.
962 CONTINUE
IF (NFLAG.GE.3) GO TO 310
IF (NFLAG.EQ.0.AND.JFLAG.EQ.1) GO TO 350
955 WRITE(6,2009) NANAL,LOY,TIMETAPE,(KM,K(K),KK+1,NUMN)
IF (NUMPC) 290,310,290
C*****READ PRESSURE B. C. FROM CARD OR TAPE*****
290 WRITE (6,2005)
DO 300 L=1,NUMPC
READ(NF,1004) IBC(L),JBC(L),PR(L)
300 WRITE (6,2007) IBC(L),JBC(L),PR(L)
310 CONTINUE
JFLAG=0
WRITE(6,4009) NFLAG,DTT
4009 FORMAT(//,NFLAG=" ",14," DTT=",F10.4//)
IF (NFLAG.GT.1) GO TO 75
WRITE(6,2025)
2025 FORMAT(//, " **NODAL DISPLACEMENTS**")
55 CONTINUE
IF (NP-1) 435,435,500
435 DO 350 N=1,NUMNL
350 MTAG(N)=1
500 CONTINUE
NCOUNT=0
DO 570 NNN=1,NP
425 NCOUNT=NCOUNT+1
C*****FORM STIFFNESS MATRIX*****
CALL STIFF
C*****CALCULATE NODAL DISPLACEMENTS*****
CALL BANSOL
IF (NCOUNT-NP) 525,510,510
510 DO 520 N=1,NUMN
C*****INITIALIZE DISPLACEMENTS*****
FF(2*N-1)=FF(2*N-1)+B(2*N-1)
520 FF(2*N)=FF(2*N)+B(2*N)
IF (NFLAG.GT.1) GO TO 925
WRITE (6,2006) (N,FF(2*N-1),FF(2*N),N=1,NUMN)
WRITE(3)(N,FF(2*N-1)+FF(2*N),N=1,NUMN)

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C.....CALCULATE STRESSES AND STRAINS.....	00001971
525 CALL CREEP	00001972
970 CONTINUE	00001973
C.....DETERMINE TIMES FOR NEXT CYCLE.....	00001974
NUMOL=NUME(LAY)	00001975
IF((NAL+1).GT.NANAL)GO TO 5000	00001976
IF(NFLAG.GT.0)NFLAG=NFLAG+2	00001977
IF(NFLAG.EQ.4)NFLAG=1	00001978
IF(NFLAG.EQ.0)GO TO 965	00001979
GO TO(967,967,967,967,970),NFLAG	00001980
969 NFLAG=0	00001981
DT=TLAST+1.-TIME	00001982
TIME=TIME+DT/2.	00001983
TIME=TLAST+1.	00001984
TLAST=TIME	00001985
DO 971 KK=1,NUMNL	00001986
971 TEMPE(KK)=TSAVE(KK)	00001987
GO TO 500	00001988
967 DT=SPTIM/24.	00001989
TIME=TIME+DT/2.	00001990
TIME=TIME+ANAL(NAL+1)-ANAL(NAL)	00001991
TIME=TIME+DT	00001992
IF(NFLAG.EQ.2)GO TO 898	00001993
GO TO 975	00001994
965 DT=ANAL(NAL+1)-ANAL(NAL)	00001995
TIME=TIME+DT/2.	00001996
TIME=TIME+DT	00001997
TLAST=TIME	00001998
898 NAL=NAL+1	00001999
NNAL=NNAL+1	00002000
NANAL=NANAL+1	00002001
400 IF(NNAL.GT.NDT)GO TO 600	00002002
IF(NNAL.EQ.1)GO TO 895	00002003
GO TO 897	00002004
600 CONTINUE	00002005
GO TO 50	00002006
941 WRITE(6,4002)TIME,TIMETAPE	00002007
4002 FORMAT(" ABORT--FIRST ANALYSIS TIME AND TAPE TIME DO NOT ",	00002008
1"AGREE! "/" TIME--- = ",F7.2/" TIMETAPE = ",F7.2)	00002009
943 WRITE(6,4003)TIME,ANAL(NAL)	00002010
4003 FORMAT(" ABORT--TIMES OF FIRST ANALYSIS GIVEN BY T1 AND ",	00002011
1"ANAL(1) DO NOT AGREE!"/"S Ti--- = ",F7.2," DAYS"/	00002012
2"ANAL(1) = ",F7.2," D AXS")	00002013
GO TO 5000	00002014
953 WRITE(6,4004)TIME,TIMETAPE	00002015
4004 FORMAT(" ABORT--NEXT ANALYSIS TIME CANNOT BE FOUND ON TAPE",	00002016
1/" TIME--- = ",F7.2," DAYS"/" TIMETAPE = ",F7.2," DAYS")	00002017
GO TO 5000	00002018
963 WRITE(6,4006)	00002019
4006 FORMAT(" NFLAG CANNOT = 5 AT STATEMENT 925+")	00002020
GO TO 5000	00002021
970 WRITE(6,4007)	00002022
	00002023
	00002024

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4007 FORMAT(1X,NFLAG CANNOT = 5 AT STATEMENT 969-")
      GO TO 5000
998 FORMAT(1X,A4,I5)
999 FORMAT(6I5,2F10.0)
1000 FORMAT(15A4)
1001 FORMAT(4I5,F10.0)
1002 FORMAT (15,F5.0,4F10.0)
1003 FORMAT(F10.0,4E10.3)
1004 FORMAT(2I5,F10.0)
1005 FORMAT(6F10.0)
1006 FORMAT(6I5,2F10.0)
1008 FORMAT(2F10.0)
1009 FORMAT(1W1)
2000 FORMAT (15A4)
1 40H0 NUMBER OF NODAL POINTS-----13/
2 40H0 NUMBER OF ELEMENTS-----13/
3 40H0 NUMBER OF DIFFERENT MATERIALS-----13/
4 40H0 NUMBER OF LAYERS IN THE STRUCTURE-----13/
5 40H0 STRAIN CAPACITY INPUT? 1-YES 0-NO ---15/
6 40H0 TIME OF FIRST ANALYSIS-----F10.4/
7 40H0 TOTAL NO. OF ANALYSES REQUESTED-----14)
2001 FORMAT (92H1ELEMENT NO.      I      J      K      L      MATERIAL      .S100002400
      1G1-RESIDUAL      SIG2-RESIDUAL      ANGLE )
2002 FORMAT (112,F12.2,2F12.3,2E24.7)
2003 FORMAT (1113,4I6,1112,2F17.3,F9.3)
2004 FORMAT (97H1NODAL POINT      TYPE X-ORDINATE Y-ORDINATE X-LOAD00002490
      1AD OR DISPLACEMENT Y LOAD OR DISPLACEMENT )
2005 FORMAT (29H0PRESSURE BOUNDARY CONDITIONS/ 24H      I      J      PRBS00002400
      1URE )
2006 FORMAT(5(26H N.P. DISPL-UX DISPL-UY )/5(15,2F10.5,1X))
2007 FORMAT (2I6,F12.3)
2008 FORMAT (50H1 NUMBER OF LAYERS IN THE ANALYSIS-----15/
1 50H0 NUMBER OF NODAL POINTS IN THE ANALYSIS-----15/
2 50H0 NUMBER OF ELEMENTS IN THE ANALYSIS-----15/
3 50H0 NUMBER OF PRESSURE CARDS FOR THE ANALYSIS-----15/
4 50H0 NUMBER OF APPROXIMATIONS FOR STRESS CALCULATION=15/
6 50H0 NUMBER OF ANALYSES AT THIS STAGE OF CONSTR-----15/
7 50H0 TIME OF LAYING THE TOP LIFT-----E10.3/
8 50H0 TIME OF LAYING THE NEXT LIFT-----F10.3)
2009 FORMAT (42H1 NODAL TEMPERATURES FOR ANALYSIS NUMBER 15,
1 " STRUCTURE UP TO LIFT " ,15," TIME FROM TAPE " ,F8.2,
2 " DAYS"/" NP. TEMP",9(13H NP. TEMP)//
3 10(15,F8.2))
2010 FORMAT (15H0 TEMP.(TIME 10X 5HE(C) 9X 6HNU 11X 4HE(T)
1 10X 5HG/H2 10X 5HALPHA/
2 (F15.3,4F15.5,E15.5))
2011 FORMAT (17H0MATERIAL NUMBER= 13, 30H1 NUMBER OF YEMP?/TIME CARDS =
113,24H1 NUMBER OF CREEP CARDS=13, 15H1 MASS DENSITY= E12.4)
2012 FORMAT (26H0NODAL POINT CARD ERROR N# 15)
2013 FORMAT (17H0 MATERIAL NUMBER 15//
1111H COEFFICIENT FUNCTIONS A(T) IN MCHENRYS EQUATION STRAIN(1) =
2STRAIN(0)+A1(T)(1-EXP(-M1*T))+A2(T)(1-EXP(-M2*T))//

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310X, 10HTMP, /TIME 11X, 24HA1, A2 FOR COMPRESS, CREEP 12X, 23HA3, A4 00002780
4FOR TENSILE CREEP// 38X, 2HA1, 11X, 2HA2, 10X, 2HA3, 11X, 2HA4// 00002780
5(10X, F10.3, 10X, E10.3, 5X, F10.3, 10X, E10.3, 5X, F10.3) 00002780
2014 FORMAT (30H0 INDEXES IN MCHEENYS EQUATION// 00002790
130H FOR COMPRESSIVE CREEP M1 = E10.3, 6X, 4HM2 = E10.3, 00002790
230H FOR TENSILE CREEP M3 = E10.3, 6X, 4HM4 = E10.3, 00002790
2017 FORMAT(" ERROR IN DISP/OR FORCE SP8C, AT NODE= ", I5) 00002790
2051 FORMAT(" NO. OF STRAIN CAPACITY PTS. = ", I4) 00002790
2052 FORMAT(" TIME-DAYS STRAIN CAP, --WIN./IN."/2(2X, F10.2)) 00002790
3000 FORMAT(15, F5.0, 2F10.0) 00002800
3007 FORMAT(12F5.0) 00002810
3017 FORMAT(12F5.0) 00002820
3009 FORMAT(F10.0) 00002830
3011 FORMAT(215, 3F10.2) 00002830
3020 FORMAT(2X, 18, F10.0) 00002830
3027 FORMAT(/" ERROR ON STRESS FREE TEMP: INPUT AT ELE, -M= ", I5) 00002830
3028 FORMAT(/" ELEMENT STRESS FREE TEMPERATURES=// 00002870
110(15, F8.2)) 00002880
3040 FORMAT(8X, F8.2) 00002890
3041 FORMAT(7(6X, F7.1)) 00002900
3029 FORMAT(1X, A8) 00002910
3030 FORMAT(A8, A8, A1) 00002920
4000 FORMAT(110, F10.0, F10.0) 00002930
4001 FORMAT(15, 515, 3F10.0) 00002940
4100 FORMAT(20X, "PERCENT MAXIMUM TENSILE STRAIN WITH RESPECT TO ", 00002950
1"STRAIN CAPACITY", /20X, 71(1H=) //25X, * - STRAIN OF STRAIN", 00002950
2" CAPACITY > OR = 75X", /24X, ** - STRAIN OF STRAIN CAPACITY" 00002970
3" > OR = 90X"//) 00002980
5000 STOP 00002990
END 00003000
SUBROUTINE QUAD 00003010
PARAMETER MXN=576, MXE=475 00003012
CHARACTER NX7*6(7), NY7*6(7) 00003015
COMMON NUMNP, NUMEL, NUMPC, N, VOL, TEMP, MTYPE, LAY, NUMN, NANAL, NP, OVER 00003020
1, NDT, NCOUNT, T1, DT, DTT, T1, TL, XC, YC, ST(3, 10), TYPLA(127), NUME(27), TUN, 00003030
2TTT(15), NUHOL, TIME, NNAL, NLAY, ISC, EX, EY, DASH, ANAL(1200), NANAL7, TLAST 00003030
3, RRR(5), ZZZ(5), NFLAG, TL1 00003050
COMMON /MATARG/ E(30, 6, 8), RO(8), EE(5), MED(15), CIC(20, 4, 8), 00003060
1CC(4, 8), NCREEP(8), SC(30, 2, 8), NSC 00003070
COMMON /ELEARG/ IX(MXE, 5), MTAG(MXE) SIG(MXE, 5), TOLD(MXE), 00003080
1DEI1(MXE), DEI2(MXE), DEI3(MXE), DEI4(MXE), DSIG(16), CCC(4), CCC(4) 00003090
2, EES(MXE, 2), EPS(6), SCAP(MXE), NE7(7), NX7, NY7, YEMPE(MXE) 00003100
COMMON /PRSARG/ IBC(100), JBC(100), PR(100) 00003110
COMMON /ORDARG/ R(MXN), Z(MXN), LR(MXN), UZ(MXN), CODE(MXN), T(MXN) 00003120
COMMON /BANARG/ MBAND, NUMBLK, B(120), A(120, 60) 00003130
COMMON /LS4ARG/ I, J, K, S(10, 10), C(3, 3), D(3, 3), H(3, 3), P(10), LM(4), 00003140
1 F(3, 3) 00003150
I=IX(N+1) 00003160
J=IX(N+2) 00003170
K=IX(N+3) 00003180
L=IX(N+4) 00003190
IX(N, 5)=IABS(IX(N, 5)) 00003200

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```

      MTYPE=IX(N,5)
C*****FORM STRESS-STRAIN RELATIONSHIP INCLUDING TIME OR*****
C*****TEMPERATURE DEPENDENCE OF ELASTIC CONSTANTS*****
      DO 15 M=1,4
      MM=IX(N,M)
      RRR(M)=R(MM)
      15 ZZZ(M)=Z(MM)
      TEM=(TEMPE(N)+TOLD(N))/2.
      IF (Y1) 50,40,50
      40 DO 103 M=2,30
      IF (E(M,1,MTYPE)-TEM) 103,104,104
      103 CONTINUE
      104 RATIO=0.0
      DEN=E(M,1,MTYPE)-E(M=1,1,MTYPE)
      IF (DEN) 70,71,70
      70 RATIO=(TEM-E(M=1,1,MTYPE))/DEN
      GO TO 71
      50 DO 55 M=2,30
      IF (E(M,1,MTYPE)-TL) 55,60,60
      55 CONTINUE
      60 RATIO=0.
      DEN=E(M,1,MTYPE)-E(M=1,1,MTYPE)
      IF (DEN) 64,71,64
      64 RATIO=(TL-E(M=1,1,MTYPE))/DEN
      71 DO 105 KK=1,5
      105 EE(KK)=E(M-1,KK+1,MTYPE)+RATIO*(E(M,KK+1,MTYPE)-E(M-1,KK+1,MTYPE))
      DO 300 KK=1,2
      300 EES(N,KK)=EE(KK)
      IF (ISC=EO,0) GO TO 76
      DO 455 MM=2,30
      IF (SC(MM,1,MTYPE)-TL1) 455,460,460
      455 CONTINUE
      460 RRAT=0.
      DDEN=SC(MM,1,MTYPE)-SC(MM-1,1,MTYPE)
      IF (DDEN) 464,471,464
      464 RRAT=(TL1-SC(MM-1,1,MTYPE))/DDEN
      471 SCAP(N)=SC(MM-1,2,MTYPE)+RRAT*(SC(MM,2,MTYPE)-SC(MM-1,
      12,MTYPE))
      76 IF (MTAG(N)-2) 80,80,81
      80 RATIO=EE(2)
      GO TO 82
      81 RATIO=EE(2)*EE(3)/EE(1)
      82 XX=EE(1)/EE(3)
      YY=1.
      IF (MTAG(N)-1) 83,83,84
      83 XX=YY
      84 IF (MTAG(N)-3) 86,86,85
      85 YY=XX
      86 CONTINUE
      UU=YY-EE(2)*RATIO
      VV=XX-EE(2)*RATIO
      UV=EE(2)*(1.+RATIO)

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      COMM=EE(1)/(VV*UU-UV*2)
      C(1,1)=UU*COMM
      C(1,2)=UV*COMM
      C(1,3)=0.
      C(2,1)=C(1,2)
      C(2,2)=VV*COMM
      C(2,3)=0.
      C(3,1)=0.
      C(3,2)=0.
      C(3,3)=EE(1)/(EE(1)/EE(3)+1.+2.*EE(2))
      THETA=SIG(N,3)/57.296
      SS=SIN(THETA)
      CO=COS(THETA)
      S2=SS*SS
      C2=CO*CO
      SCO=SS*CO
      DO 87 II=1,3
      DO 87 JJ=1,3
87  F(II,JJ)=C(II,JJ)
      D(1,1)=C2
      D(1,2)=S2
      D(1,3)=SCO
      D(2,1)=S2
      D(2,2)=C2
      D(2,3)=-SCO
      D(3,1)=-2.*SCO
      D(3,2)=-D(3,1)
      D(3,3)=C2-S2
      DO 88 II=1,3
      DO 88 JJ=1,3
      H(II,JJ)=0.0
      DO 88 KK=1,3
88  H(II,JJ)=H(II,JJ)+C(II,KK)*D(KK,JJ)
      DO 89 II=1,3
      DO 89 JJ=1,3
      C(II,JJ)=0.0
      DO 89 KK=1,3
89  C(II,JJ)=C(II,JJ)+D(KK,II)*H(KK,JJ)
      DO 100 II=1,10
      P(II)=0.0
      DO 100 JJ=1,10
100  S(II,JJ)=0.0
      DO 150 II=1,3
      DO 150 JJ=1,10
150  ST(II,JJ)=0.0
      VOL=0.0
      C*****FORM STIFFNESS FOR A CST TRIANGULAR ELEMENT*****
      VOL=0.0
      IF(IX(N,3).NE.IX(N,4))GO TO 700
      CALL STFTRI(1,2,3)
      XC=(R(1)+R(J)+R(K))/3.
      YC=(Z(1)+Z(J)+Z(K))/3.

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C*****FORM STIFFNESS FOR A CST QUADRILATERAL ELEMENT*****
GO TO 701
700 XC=(R(I)+R(J)+R(K)+R(L))/4.
    YC=(Z(I)+Z(J)+Z(K)+Z(L))/4.
    RRR(5)=XC
    ZZZ(5)=YC
    CALL STFTRI(4,1,5)
    CALL STFTRI(1,2,5)
    CALL STFTRI(2,3,5)
    CALL STFTRI(3,4,5)
C*****CALCULATE UNBALANCED LOADS DUE TO TEMPERATURE CHANGE***
C*****AND STRESS RELAXATION*****
701 TEMP=(TEMPE(N)-TOLD(N))*EE(5)
    IF(TIME 170,160,170)
160 TEMP=0.
170 CONTINUE
    DSIG(1)=SIG(N,1)*C2+SIG(N,2)*S2
    DSIG(2)=SIG(N,1)*S2+SIG(N,2)*C2
    DSIG(3)=(SIG(N,1)-SIG(N,2))*SC0
    DO 190 JJ=1,3
190 DSIG(JJ)=-DSIG(JJ)*(C(JJ,1)+C(JJ,2))*TEMP
    DO 200 II=1,10
    DO 200 JJ=1,3
200 P(II)=P(II)+DSIG(JJ)*ST(JJ,II)*VOL
C*****ADD SHEAR STIFFNESS OF FOUNDATION*****
    IF(IX(N,3).EQ.IX(N,4))GO TO 510
    COMM=VOL*EE(4)
    S(9,9)=S(9,9)+COMM
    S(10,10)=S(10,10)+COMM
C*****ELIMINATE CENTER POINT*****
DO 500 K=1,2
    IH=10-K
    ID=IH+1
    DO 500 I=1,IH
    S(ID,I)=S(ID,I)/S(ID,ID)
    P(I)=P(I)-P(ID)*S(I,ID)/S(ID,ID)
    DO 500 J=1,IH
500 S(J,I)=S(J,I)-S(J,ID)*S(ID,I)
C*****CALCULATE LOADS DUE TO GRAVITY*****
510 CONTINUE
    IF(N=NUMOL) 580,580,540
540 IF(NNAL.GT.1)GO TO 580
    IF(NNAL.EQ.1.AND.NFLAG.GT.2)GO TO 580
550 IMUL=4
    IF(IX(N,3).EQ.IX(N,4))IMUL=3
    AMUL=IMUL
    DO 560 I=1,IMUL
560 P(2*I)=P(2*I)-RO(MTYPE)*VOL/AMUL
580 CONTINUE
130 RETURN
END
SUBROUTINE ONED

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PARAMETER MXN=576,MXB=475
CHARACTER NX7*6(7),NX7*6(7)
COMMON NUMNP,NUMEL,NUMPC,N,VOL,TEMP,MTYPE,LAY,NUMN,NANAL,NP,OVER
1,NDT,NCOUNT,TI,DT,DTI,T1,TL,XC,YC,ST(3,10),TIMLA(27),NUME(27),TIP,
2TTT(15),NUMOL,TIME,NNAL,NLAY,ISC,EX,EY,DASH,ANAL(200),NANAL1,TLAST
3,RRR(5),ZZZ(5),NFLAG,TL1
COMMON /MATARG/ E(30,6,8),RO(8),EE(5),HED(15),CIC(20,4,8),
1CC(4,8),NCREEP(8),SC(30,2,8),NSC
COMMON /ELEARG/ IX(MXE,5),MTAG(MXE),SIG(MXE,5),TOLD(MXE),
1DE11(MXE),DE12(MXE),DE21(MXE),DE22(MXE),DSIG(6),CCO(4),CCC(4)
2,EES(MXE,2),EPS(6),SCAP(MXE),NE7(7),NX7,NY7,YEMPE(MXE)
COMMON /PRSARG/ JBC(100),JBC(100),PR(100)
COMMON /ORDARG/ R(MXN),Z(MXN),LR(MXN),UZ(MXN),CODE(MXN),T(MXN)
COMMON /BANARG/ MBAND,NUMBLK,B(120),A(120,60)
COMMON /LS4ARG/ I,J=K,S(10,10),C(3,3),D(3,3),H(3,3),P(10),LM(4),
1 F(3,3)
DO 100 I=1,8
P(I)=0.0
DO 100 J=1,8
100 S(I,J)=0.0
MTYPE=IX(N,5)
I=IX(N,1)
J=IX(N,2)
DX=R(J)-R(I)
DY=Z(J)-Z(I)
XL=SQRT(DX**2+DY**2)
COSA=DX/XL
SINA=DY/XL
COMM=E(1,2,MTYPE)*E(1,5,MTYPE)/XL
S(1,1)=COSA*COSA*COMM
S(1,2)=COSA*SINA*COMM
S(1,3)=-S(1,1)
S(1,4)=-S(1,2)
S(2,1)=S(1,2)
S(2,2)=SINA*SINA*COMM
S(2,3)=-S(1,2)
S(2,4)=-S(2,2)
S(3,1)=S(1,3)
S(3,2)=S(2,3)
S(3,3)=S(1,1)
S(3,4)=S(1,2)
S(4,1)=S(1,4)
S(4,2)=S(2,4)
S(4,3)=S(3,4)
S(4,4)=S(2,2)
EP=SIG(N,1)/E(1,2,MTYPE)
DX=DX*EP
DY=DY*EP
P(1)=S(1,1)*DX+S(1,2)*DY
P(2)=S(2,1)*DX+S(2,2)*DY
P(3)=-P(1)
P(4)=-P(2)

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AD-A069 376

ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MISS F/G 13/13
VERIFICATION OF TEMPERATURE AND THERMAL STRESS ANALYSIS COMPUTE--ETC(U)
MAR 79 T C LIU, R L CAMPBELL, A A BOMBICH

UNCLASSIFIED

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RETURN
END
SUBROUTINE STFTRI(I1,JJ,KK)
PARAMETER MXN=576,MXE=475
CHARACTER NX7*6(7),NX7*6(7)
STIFFNESS MATRIX (S) AND TRANSFORMATION MATRIX (B) FOR CST ELEMENT
ARGUMENTS (1,2,3) FOR TRIANGLE
(4,4,5),(1,2,5),(2,3,5)AND(3,4,5) FOR QUADRILATERAL
COMMON NUMNP,NUMEL,NUMPC,NN,VOL,TEMP,TYPE,LAY,NUMN,NANAL,NP,OVER
1,NDT,NCOUNT,TI,DT,DTI,T1,TL,XC,YC,ST(3,10),TIMLA(27),NUME(27),TIP,
2TTT(15),NUMOL,TIME,NNAL,NLAY,ISC,EX,EY,DASH,ANAL(200),NANAL,TLAST
3,RRR(5),ZZZ(5),NFLAG=TL1
COMMON /ELEARG/ IX(MXE,5),MTAG(MXE),SIG(MXE,5),TOLD(MXE),
1DE11(MXE),DE12(MXE),DE21(MXE),DE22(MXE),DSIG(6),CCO(4),CCC(4)
2,EES(MXE,2),EPS(6),SCAP(MXE),NE7(7),NX7,NY7,TEMPE(MXE)
COMMON /ORDARG/ R(MXN),Z(MXN),LR(MXN),UZ(MXN),CODE(MXN),T(MXN)
COMMON/LSARG/ IN,JN,KN,S(10,10),C(3,3),DUM(18),P(10),LM(4),
1F(3,3)
DIMENSION RR(4),ZZ(4),D(4,6),B(3,10),ANGLE(4),F(3,10)
1. INITIALIZATION
LM(1)=II
LM(2)=JJ
LM(3)=KK
RR(1)=RRR(II)
RR(2)=RRR(JJ)
RR(3)=RRR(KK)
ZZ(1)=ZZZ(II)
ZZ(2)=ZZZ(JJ)
ZZ(3)=ZZZ(KK)
DO 30 I=1,3
DO 20 J=1,10
F(I,J) = 0.0
20 B(I,J) = 0.0
DO 30 J=1,6
30 D(I,J) = 0.0
2. AREA OF TRIANGLE
COMM=RR(2)*(ZZ(3)-ZZ(1))+RR(1)*(ZZ(2)-ZZ(3))+RR(3)*(ZZ(1)-ZZ(2))
XI = COMM*2.0
VOL=VOL*XI
3. FORM COEFFICIENT-DISPLACEMENT MATRIX (B)
D(1,1)= (ZZ(2)-ZZ(3))/COMM
D(1,3)= (ZZ(3)-ZZ(1))/COMM
D(1,5)= (ZZ(1)-ZZ(2))/COMM

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	D(2,2)= (RR(3)-RR(2))/COMM	00006420
	D(2,4)= (RR(1)-RR(3))/COMM	00006430
	D(2,6)= (RR(2)-RR(1))/COMM	00006440
	D(3,1)=D(2,2)	00006450
	D(3,2)=D(1,1)	00006460
	D(3,3)=D(2,4)	00006470
	D(3,4)=D(1,3)	00006480
	D(3,5)=D(2,6)	00006490
	D(3,6)=D(1,5)	00006500
C		00006510
C	FORM (B)	00006520
C		00006530
	DO 50 I=1,3	00006540
	DO 50 J=1,3	00006550
	K = 2*LM(J)	00006560
	L = 2*J	00006570
	B(I,K-1)=D(I,L-1)	00006580
	50 B(I,K)= D(I,L)	00006590
C		00006600
C	ROTATE UNKNOWNNS IF REQUIRED	00006610
C		00006620
	DO 118 M=1,4	00006630
	MM=IX(NN,M)	00006640
	118 ANGLE(M)=CODE(MM)/57.2958	00006650
	LL=2	00006660
	IF(IX(NN,3).EQ. IX(NN,4)) LL=3	00006670
	DO 125 J=1,LL	00006680
	I=LM(J)	00006690
	IF(ANGLE(I).GE. 0.0) GO TO 125	00006700
	SINA=SIN(ANGLE(I))	00006710
	COSA=COS(ANGLE(I))	00006720
	IJ = 2*J	00006730
	DO 124 K=1,3	00006740
	TEM = B(K,IJ-1)	00006750
	B(K,IJ-1)=TEM*COSA*B(K,IJ)*SINA	00006760
	124 B(K,IJ) =-TEM*SINA*B(K,IJ)*COSA	00006770
	125 CONTINUE	00006780
C		00006790
C	4. FORM ELEMENT STIFFNESS MATRIX (B)*T*(C)*(B)	00006800
C		00006810
	DO 130 J=1,10	00006820
	DO 130 K=1,3	00006830
	IF(B(K,J).EQ. 0.0) GO TO 130	00006840
	DO 129 I=1,3	00006850
	129 F(I,J)=F(I,J)+C(I,K)*B(K,J)*XI	00006860
	130 CONTINUE	00006870
C		00006880
	DO 140 I=1,10	00006890
	DO 140 K=1,3	00006900
	IF(B(K,I).EQ. 0.0) GO TO 140	00006910
	DO 139 J=1,10	00006920
	139 S(I,J)=S(I,J)+B(K,I)*F(K,J)	00006930

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140 CONTINUE	00006980
C 5. TRANSFER OR ACCUMULATE (B) IN (ST) MATRIX	00006982
C	00006980
DO 200 I=1,3	00006970
DO 200 J=1,10	00006980
200 ST(I,J)=ST(I,J)+B(I,J)	00006990
C	00007000
C CHECK FOR LAST CALL FOR QUADRILATERAL	00007020
C	00007020
IF(I1,60,3) GO TO 250	00007080
RETURN	00007090
250 DO 260 I=1,3	00007090
DO 260 J=1,10	00007080
260 ST(I,J) = ST(I,J)/4.0	00007070
C	00007080
RETURN	00007090
C	00007100
END	00007110
SUBROUTINE STIFF	00007120
PARAMETER MXN=576,MXB=475	00007120
CHARACTER NX7*6(7),NY7*6(7)	00007185
COMMON NUMNP,NUMEL,NUMPC,N,VOL,TEMP,MTYPE,LAY,NUMN,NANAL,NP,OVER	00007190
1,NDT,NCOUNT,TI,DT,DTT,Y1,TL,XC,YC,ST(3,10),TYPLA(27),NUME(27),TIP,	00007150
2TTT(15),NUMOL,TIME,NMAL,NLAY,ISC,EX,EY,DASH,NAL(200),NANAL,TLAST	00007180
3,RRR(5),ZZZ(5),NFLAG,TL1	00007185
COMMON /MATARG/ E(30,6,8),RO(8),EE(5),HED(15),CIC(20,4,8),	00007170
1CC(4,8),NCREEP(8),SC(30,2,8),NSC	00007180
COMMON /ELEARG/ IX(MXE,5),HTAG(MXE),SIG(MXE,5),TOLD(MXE),	00007190
1DE11(MXE),DE12(MXE),DE21(MXE),DE22(MXE),DSIG(6),CCO(4),CCC(4)	00007200
2,EE5(MXE,2),EPS(6),SCAP(MXE),NE7(7),NX7,NY7,YEMPE(MXE)	00007220
COMMON /PRSARG/ IBC(100),JBC(100),PR(100)	00007220
COMMON /ORDARG/ R(MXN),Z(MXN),UR(MXN),UZ(MXN),CODE(MXN),T(MXN)	00007280
COMMON /BANARG/ MBAND,NUMBLK,B(120),A(120,60)	00007290
COMMON /L84ARG/ I,J,K,S(10,10),C(3,3),D(3,3),H(3,3),P(10),LH(4),	00007250
1 F(3,3)	00007280
C*****INITIALIZATION*****	00007281
REWIND 2	00007270
NB=30	00007280
ND=2*NB	00007290
ND2=2*ND	00007300
STOP=0.0	00007320
NUMBLK=0	00007320
DO 50 N=1,ND2	00007320
B(N)=0.0	00007390
DO 50 M=1,ND	00007350
50 A(N,M)=0.0	00007380
C*****FORM STIFFNESS MATRIX IN BLOCKS*****	00007361
60 NUMBLK=NUMBLK+1	00007370
NH=NB*(NUMBLK+1)	00007380
NM=NH-NB	00007390
NL=NH-NB+1	00007400

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KSHIFT=2*NL-2	00007420
N1=1	00007420
DO 220 M=1,LAY	00007420
TL=TIME-TIMLA(M)	00007420
TL1=TIME-TIMLA(M)	00007421
N2=NUME(M)	00007420
DO 210 N=N1,N2	00007420
IF (IX(N,5)) 210,210,65	00007420
65 DO 80 I=1,4	00007420
IF (IX(N,I)-NL) 80,70,70	00007420
70 IF (IX(N,I)-NM) 90,90,80	00007520
80 CONTINUE	00007520
GO TO 210	00007520
90 IF (IX(N,3)-IX(N,2)) 92,91,92	00007520
91 CALL ONED	00007520
GO TO 165	00007520
92 CALL QUAD	00007520
IF (VOL) 164,164,165	00007520
164 WRITE (6,2003) N	00007520
C*****ADD ELEMENT STIFFNESS TO TOTAL STIFFNESS*****	00007521
165 IX(N,5)=-IX(N,5)	00007520
DO 166 I=1,4	00007600
166 LM(I)=2*IX(N,I)-2	00007600
DO 200 I=1,4	00007600
DO 200 K=1,2	00007600
II=LM(I)+K-KSHIFT	00007600
KK=2*I-2+K	00007600
B(II)=B(II)+P(KK)	00007600
DO 200 J=1,4	00007600
DO 200 L=1,2	00007600
JJ=LM(J)+L-II+1-KSHIFT	00007600
LL=2*J-2+L	00007600
IF (JJ) 200,200,175	00007720
175 IF (ND-JJ) 180,195,195	00007720
180 WRITE (6,2004) N	00007720
STOP=1.0	00007720
GO TO 210	00007720
195 A(II,JJ)=A(II,JJ)+S(MK,LL)	00007720
200 CONTINUE	00007720
210 CONTINUE	00007720
N1=N2+1	00007720
IF (N1-NUMEL) 220,220,225	00007820
220 CONTINUE	00007821
C*****ADD CONCENTRATED FORCES WITHIN BLOCK*****	00007820
225 DO 255 N=NL,NM	00007820
K=2*N-KSHIFT	00007820
B(K)=B(K)+UZ(N)	00007820
B(K-1)=B(K-1)+UR(N)	00007820
IF (NCOUNT-NP) 255,250,250	00007820
250 IF (N-NUMN) 252,252,255	00007820
252 UZ(N)=0,	00007820
UR(N)=0,	00007820

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255 CONTINUE	00007980
C*****BOUNDARY CONDITIONS*****	00007981
C*****1.PRESSURE B. C.	00007983
IF (NUMPC) 260,310,260	00007980
260 DO 300 L=1,NUMPC	00007980
I=IB(L)	00007980
J=JB(L)	00007980
PP=PR(L)/2.	00007980
DZ=(Z(I)-Z(J))*PP	00007980
DR=(R(J)-R(I))*PP	00007970
264 II=2*I-KSHIFT	00007980
JJ=2*J-KSHIFT	00007980
IF (II) 280,280,265	00008000
265 IF (JJ-ND) 270,270,280	00008000
270 SINA=0.0	00008000
COSA=1.0	00008000
IF (CODE(I)) 271,272,272	00008000
271 SINA=SIN(CODE(I)/57.3)	00008000
COSA=COS(CODE(I)/57.3)	00008000
272 B(II-1)=B(II-1)+(COSA*DZ+SINA*DR)	00008000
B(II)=B(II)-(SINA*DZ-COSA*DR)	00008000
280 IF (JJ) 300,300,285	00008000
285 IF (JJ-ND) 290,290,300	00008100
290 SINA=0.0	00008100
COSA=1.0	00008100
IF (CODE(J)) 291,292,292	00008100
291 SINA=SIN(CODE(J)/57.3)	00008100
COSA=COS(CODE(J)/57.3)	00008100
292 B(JJ-1)=B(JJ-1)+(COSA*DZ+SINA*DR)	00008100
B(JJ)=B(JJ)-(SINA*DZ-COSA*DR)	00008100
300 CONTINUE	00008100
C*****2.DISPLACEMENT B. C.	00008100
310 DO 400 M=NL,NH	00008100
IF (M-NUMN) 315,315,400	00008200
315 U=UR(M)	00008200
N=2*M-1-KSHIFT	00008200
IF (CODE(M)) 390,400,316	00008200
316 IF (CODE(M)-1.) 317,370,317	00008200
317 IF (CODE(M)-2.) 318,390,318	00008200
318 IF (CODE(M)-3.) 390,380,390	00008200
370 CALL MODIFY(A,B,ND2,MBAND,N,U)	00008200
GO TO 400	00008200
380 CALL MODIFY(A,B,ND2,MBAND,N,U)	00008200
390 U=UZ(M)	00008300
N=N+1	00008300
CALL MODIFY(A,B,ND2,MBAND,N,U)	00008300
400 CONTINUE	00008300
C*****WRITE BLOCK OF EQUATIONS ON DISK, SHIFT UP LOWER BLOCK**	00008300
WRITE (2) (B(N),(A(N,M),M=1,MBAND),N=1,ND)	00008300
DO 420 N=1,ND	00008300
K=N-ND	00008300
B(N)=B(K)	00008300

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B(K)=0.0	00000300
DO 420 M=1,ND	00000310
A(N,M)=A(K,M)	00000340
420 A(K,M)=0.0	00000340
C*****CHECK FOR LOWER BLOCK*****	00000341
IF (NM=NUMN) 60,400,480	00000340
480 CONTINUE	00000340
IF (STOP) 490,500,490	00000340
490 CALL EXIT	00000340
500 RETURN	00000340
2003 FORMAT (26H0NEGATIVE AREA ELEMENT NO. 14)	00000340
2004 FORMAT (29H0BAND WIDTH EXCEEDS ALLOWABLE 14)	00000340
END	00000340
SUBROUTINE MODIFY(A,B,NEQ,MBAND,N,U)	00000350
DIMENSION A(120,60),B(120)	00000350
DO 250 M=2,MBAND	00000350
K=N-M+1	00000350
IF (K) 235,235,230	00000350
230 B(K)=B(K)-A(K,M)*U	00000350
A(K,M)=0.0	00000350
235 K=N-M-1	00000350
IF (NEQ-K) 250,240,240	00000350
240 B(K)=B(K)-A(N,M)*U	00000350
A(N,M)=0.0	00000350
250 CONTINUE	00000350
A(N,1)=1.0	00000350
B(N)=U	00000350
RETURN	00000350
END	00000350
SUBROUTINE BANSOL	00000350
COMMON /BANARG/ MM,NUMBLK,B(120),A(120,60)	00000350
NN=60	00000350
NL=NN+1	00000350
NH=NN+NN	00000350
REWIND 1	00000350
REWIND 2	00000350
NB=0	00000350
GO TO 150	00000350
C*****REDUCE EQUATIONS BY BLOCKS*****	00000351
C*****1. SHIFT BLOCK OF EQUATIONS	00000352
100 NB=NB+1	00000350
DO 125 N=1,NN	00000350
NM=NN+N	00000350
B(N)=B(NM)	00000350
B(NM)=0.0	00000350
DO 125 M=1,MM	00000350
A(N,M)=A(NM,M)	00000350
125 A(NM,M)=0.0	00000350
C*****2. READ NEXT BLOCK OF EQUATIONS INTO CORE	00000351
IF (NUMBLK-NB) 150,200,150	00000350
150 READ (2) (B(N), (A(N,M), M=1,MM), N=NL,NH)	00000350
IF (NB) 200,100,200	00000350

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C.....3. REDUCE BLOCK OF EQUATIONS
200 DO 300 N=1,NN
    IF (A(N,1)) 225,300,225
225 B(N)=B(N)/A(N,1)
    DO 275 L=2,MM
    IF (A(N,L)) 230,275,230
230 C=A(N,L)/A(N,1)
    I=N-L-1
    J=0
    DO 250 K=L,MM
    J=J+1
250 A(I,J)=A(I,J)-C*A(N,K)
    B(I)=B(I)-A(N,L)*B(N)
    A(N,L)=C
275 CONTINUE
300 CONTINUE
C.....4. WRITE BLOCK OF EQUATIONS ON DISK 2.....
    IF (NUMBLK-NB) 375,400,375
375 WRITE (1) (B(N), (A(N,M), M=2,MM), N=1,NN)
    GO TO 100
C.....BACK SUBSTITUTION.....
400 DO 450 M=1,NN
    N=NN+1-M
    DO 425 K=2,MM
    L=N-K-1
425 B(N)=B(N)-A(N,K)*B(L)
    NM=N-NM
    B(NM)=B(N)
450 A(NM,NB)=B(N)
    NB=NB-1
    IF (NB) 475,500,475
475 BACKSPACE 1
    READ (1) (B(N), (A(N,M), M=2,MM), N=1,NN)
    BACKSPACE 1
    GO TO 400
C.....ORDER UNKNOWN IN B ARRAY.....
500 K=0
    DO 600 NB=1,NUMBLK
    DO 600 N=1,NN
    NM=N-NM
    K=K+1
600 B(K)=A(NM,NB)
    RETURN
    END
    SUBROUTINE CREEP
    PARAMETER MXN=576, MxE=475
    CHARACTER NX7*6(7), NX7*6(7)
    COMMON NUMNP, NUMEL, NUMPC, N, VOL, TEMR, MTYPE, LAY, NUMN, NANAL, NP, OVER
    1, NDT, NCOUNT, TI, DT, DTT, T1*TL, XC, YC, ST(3,10), TIMPLA(27), NUME(27), TDP,
    2TTT(15), NUMOL, TIME, NMAL, NLABY, ISC, EX, EY, DASH, ANAL(200), NANALT, LAST
    3, RRR(5), ZZZ(5), NFLAG*TL1
    COMMON /MATARG/ E(30,6,8), RO(8), EE(8), HED(15), CIC(20,4,8),

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1CC(4,8),NCREEP(8),SC(30,2,8),NSC                                00009320
COMMON /ELEARG/ IX(MXE,9),HTAG(MXE),SIG(MXE,2),TOLD(MXE),        00009330
1DE11(MXE),DE12(MXE),DE21(MXE),DE22(MXE),DSIG(6),CCQ(4),CCC(4)    00009340
2,EES(MXE,2),EPS(6),SGAP(MXE),NE7(7),NX7,NY7,YEMPE(MXE)          00009350
COMMON /PRSARG/ IBC(100),JBC(100),PR(100)                        00009360
COMMON /ORDARG/ R(MXN),Z(MXN),UR(MXN),UZ(MXN),CODE(MXN),T(MXN)    00009370
COMMON /BANARG/ MBAND,NUMBLK,B(120),A(120,60)                    00009380
COMMON /LS4ARG/ I,J,K,S(10,10),C(5,3),D(3,3),H(3,3),P(10),LH(4), 00009390
1F(3,3)                                                            00009400
CHARACTER DASH=6,OVER=6,ETH=1(2)                                00009410
MPRINT=0                                                            00009420
N1=1                                                                00009430
IC=1                                                                00009440
DO 600 MM=1,LAY                                                    00009450
N2=NUME(M)                                                         00009460
DO 550 MM=N1,N2                                                    00009470
N=MM                                                                00009480
TL=TIME-TIMLA(M)                                                    00009490
TLI=TIME-TIMLA(M)                                                  00009491
C*****EVALUATE ELEMENT STRESSES*****00009492
CALL STRESS                                                         00009493
IF (IX(N,2)-IX(N,3)) 255,104,255                                  00009494
255 HTAG(N)=1                                                       00009495
IF (DSIG(4)) 104,104,259                                           00009496
259 IF (DSIG(4)+DSIG(5)) 260,260,261                               00009497
260 HTAG(N)=2                                                       00009498
GO TO 104                                                           00009499
261 HTAG(N)=3                                                       00009500
265 IF (DSIG(5)) 104,104,266                                         00009501
266 HTAG(N)=4                                                       00009502
104 IF (NFLAG.GT.1)GO TO 106                                         00009503
IF (MPRINT) 106,106,106                                             00009504
105 IF (ISC.EQ.0)GO TO 750                                           00009505
WRITE(6,2005)DT                                                     00009506
WRITE(6,2000)LAY,NANAL,TIME,NCOUNT                                  00009507
WRITE(2,2007)LAY,NANAL,TIME,DT                                      00009508
GO TO 760                                                            00009509
750 WRITE(6,2005)DT                                                  00009510
WRITE(6,2002)LAY,NANAL,TIME,NCOUNT                                  00009511
760 WRITE(3)LAY,NANAL,TIME,NCOUNT                                    00009512
MPRINT=50                                                            00009513
106 CONTINUE                                                         00009514
C*****CALCULATE ELEMENT STRAINS*****00009515
EPS(1)=((1./EES(N,1))*((1.-EES(N,2))*2)+DSIG(1)-EES(N,2))          00009516
1*(1.-EES(N,2))*DSIG(2))                                             00009517
EPS(2)=((1./EES(N,1))*((1.-EES(N,2))*2)+DSIG(2)-EES(N,2))          00009518
1*(1.-EES(N,2))*DSIG(1))                                             00009519
EPS(3)=((2.-EES(N,2))*DSIG(3))/EES(N,1)                            00009520
EPST1=(EPS(1)+EPS(2))/2.                                             00009521
EPST2=.5*(SQRT(((EPS(1)-EPST1)**2)+(EPS(2)-EPST1)**2))              00009522
EPS(4)=EPST1+EPST2                                                  00009523
EPS(5)=EPST1-EPST2                                                  00009524

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SDIFF=EPS(1)-EPS(2)
EPS(6)=ATAN2(EPS(3),SDIFF)/2.
EPS(6)=57.296*EPS(6)
DO 700 IIE=1,5
700 EPS(IIE)=EPS(IIE)*1000000.
EABREVRES(N,1)/1000000.
IF(NFLAG.GT.1)GO TO 751
DO 759 JL=1,2
IF(EPS(JL))755,755,756
755 ETR(JL)=1H
GO TO 759
756 ETR(JL)=1H*
759 CONTINUE
C*****COMPARE STRAIN TO STRAIN CAPACITY IF APPLICABLE*****
IF(ISC.EQ.0)GO TO 305
IF(EPS(4)-0.)706,706,705
705 NSX=(EPS(4)/SCAP(N))*100.+9.5
IF(NSX.GE.1000)GO TO 720
IF(NSX.LT.75)GO TO 725
IF(NSX.GE.90)GO TO 726
ENCODE(NX7(IC),729)" ",NSX," "
729 FORMAT(A1,13,A2)
GO TO 709
726 ENCODE(NX7(IC),729)" ",NSX," "
GO TO 709
725 ENCODE(NX7(IC),729)" ",NSX," "
GO TO 709
720 NX7(IC)=OVER
GO TO 709
706 NX7(IC)=DASH
NSX=0
NY7(IC)=" --- "
GO TO 740
709 ENCODE(NY7(IC),736)" ",EPS(6)
736 FORMAT(A1,F5.1)
740 NE7(IC)=N
IF(IC.EQ.7.OR.N.EQ.NUME(LAY))GO TO 730
IC=IC+1
GO TO 761
730 WRITE(7,742)(NE7(I),NX7(I),NY7(I),I=1,IC)
742 FORMAT(7(1X,15,2(A6)))
IC=1
761 WRITE(6,2001)N,XC,YC,(DSIG(I),I=1,6),EPS(1),ETR(1),EPS(2),
1ETR(2),EPS(1),I=3,6),EABREVRES(N,2),SCAP(N)
WRITE(3)N,XC,YC,(DSIG(I),I=1,6),(EPS(I),I=1,6),
1(EES(N,I),I=1,2),SCAP(N)
GO TO 751
305 WRITE(6,2003)N,XC,YC,(DSIG(I),I=1,6),(EPS(I),I=1,6),EABREV
1,EES(N,2)
WRITE(3)N,XC,YC,(DSIG(I),I=1,6),(EPS(I),I=1,6)
1,(EES(N,I),I=1,2)
C*****RELAX STRESS FOR CREEP WITH CONSTANT STRAIN-FOR NCREEP>0

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00010200
00010210
00010220
00010230
00010240
00010250
00010260
00010270
00010280
00010290
00010300
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00010350
00010360
00010370
00010371

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C*****
751 IF (NCGUNT-NP) 550,50,50 00010372
50 IF (IX(N,2)-IX(N,3)) 55,550,55 00010380
C*****INTERPOLATION OF CREEP CONSTANTS***** 00010390
55 I=IX(N,1) 00010391
J=IX(N,2) 00010400
K=IX(N,3) 00010410
L=IX(N,4) 00010420
IX(N,5)=IABS(IX(N,5)) 00010430
MTYPE=IX(N,5) 00010440
TOLD(N)=TEMPE(N) 00010450
IF (NCREEP(MTYPE)) 250,250,60 00010470
60 NCR=NCREEP(MTYPE) 00010480
IF (T1) 120,110,120 00010490
110 TL=TEMPE(N) 00010500
120 DO 140 NN=2,NCR 00010510
IF (TL-TTT(NN)) 125,150,140 00010520
125 TM=TTT(NN)-TTT(NN-1) 00010530
DIFF= TL-TTT(NN-1) 00010540
DO 130 KK=1,4 00010550
130 CCO(KK)=CIC(NN-1,KK,MTYPE)*DIFF*(CIC(NN,KK,MTYPE)-CIC(NN-1,KK,MTYPE) 00010560
1E)/TM 00010570
GO TO 160 00010580
140 CONTINUE 00010590
150 DO 155 KK=1,4 00010600
155 CCO(KK)=CIC(NN,KK,MTYPE) 00010610
160 DO 165 KK=1,4 00010620
165 CCC(KK)=CCO(KK,MTYPE) 00010630
C*****SELECT APPROPRIATE CONSTANTS***** 00010640
IF (DSIG(4)) 170,170,175 00010650
170 KK=1 00010660
GO TO 180 00010670
175 KK=3 00010680
180 CCO1=CCO(KK) 00010690
CCO2=CCO(KK+1) 00010700
CCO3=CCO1 00010710
CCO4=CCO2 00010720
CCC1=CCC(KK) 00010730
CCC2=CCC(KK+1) 00010740
CCC3=CCC1 00010750
CCC4=CCC2 00010760
IF (DSIG(5)) 185,185,190 00010770
185 CCO3=CCO(1) 00010780
CCO4=CCO(2) 00010790
CCC3=CCC(1) 00010800
CCC4=CCC(2) 00010810
190 CONTINUE 00010820
C*****MODIFICATION OF STRESSES TO ALLOW FOR CREEP RELAXATION** 00010821
C*****OF STRESS AT CONSTANT STRAIN ON THE APPLICATION OF A*** 00010822
C*****TIME INCREMENT***** 00010823
THETA=(DSIG(6)-SIG(N*3))/57.296 00010830
CO=COS(THETA) 00010840

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SS=SIN(THETA)
C2=C0-C0
S2=SS-SS
S101=C2*(SIG(N,4)+S16(N,1))+S2*(S16(N,5)+SIG(N,2))
S102=S2*(SIG(N,4)+S16(N,1))+C2*(S16(N,5)+SIG(N,2))
IF (T1) 194,191,192
191 DE11(N)=DSIG(4)*CCC2*CC02
DE12(N)=DSIG(4)*CCC1*CC01
DE21(N)=DSIG(5)*CCC4*CC04
DE22(N)=DSIG(5)*CCC3*CC03
GO TO 195
192 DET11= C2*DE11(N)+S2*DE21(N)
DET12= C2*DE12(N)+S2*DE22(N)
DET21= S2*DE11(N)+C2*DE21(N)
DET22= S2*DE12(N)+C2*DE22(N)
DE11(N)= DET11+(DSIG(4)-SIG1)*CCC2*CC02
DE12(N)= DET12+(DSIG(4)-SIG1)*CCC1*CC01
DE21(N)= DET21+(DSIG(5)-SIG2)*CCC4*CC04
DE22(N)= DET22+(DSIG(5)-SIG2)*CCC3*CC03
195 CONTINUE
SIG(N,1)=0.
SIG(N,2)=0.
TR=0.
220 TR=TR+DTT
DELTA1=(DE11(N)+DE12(N))*DTT
DELTA2=(DE21(N)+DE22(N))*DTT
SIG1=DELTA1*F(1,1)
SIG2=DELTA2*F(2,2)
SIG(N,1)=SIG(N,1)-SIG1
SIG(N,2)=SIG(N,2)-SIG2
C****CALCULATION OF CREEP RATES FOR THE NEXT TIME INTERVAL***
DE11(N)= DE11(N)*(1.-DTT*CCG2)
DE12(N)= DE12(N)*(1.-DTT*CCG1)
DE21(N)= DE21(N)*(1.-DTT*CCG4)
DE22(N)=DE22(N)*(1.-DTT*CCG3)
DE11(N)=DE11(N)-SIG1*CCC2*CC02
DE12(N)=DE12(N)-SIG1*CCC1*CC01
DE21(N)=DE21(N)-SIG2*CCC4*CC04
DE22(N)=DE22(N)-SIG2*CCC3*CC03
C
IF (TR-DT) 220,250,250
250 SIG(N,3)=DSIG(6)
SIG(N,4)=DSIG(4)
SIG(N,5)=DSIG(5)
250 CONTINUE
N1=N2+1
IF (N1-NUMEL) 600,600,650
600 CONTINUE
650 CONTINUE
RETURN
2005 FORMAT(1H1," PRESENT TIME INCREMENT="DT,"F7.2," DAYS")
2000 FORMAT(" NO. OF LIFTS/OR TIME SPANS=",15," ANALYSIS ",
1,"CYCLE N=",9(1H-),15,20X,"*KEY FOR CHARACTER POSITION")

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2" FOLLOWING EPI-X & EPI-Y BELOW**("STRESS AND STRAINS",
3" AFTER---",F7.2," DAYS",14X," TENSILE STRAIN"/
4" APPROXIMATION NO.",10(1H-),15,20X,9BLANK = COMPR. STRAIN",
5/" ELEM",
6" CENTROID-IN. ",18(1H-),18(1H-),18(1H-),18(1H-),
7"MICROSTRAINS",14(1H-),18(1H-),18(1H-),18(1H-),
8" NO. X-ORD Y-ORD SIG-X SIG-Y SIG-XY SIG=1 SIG",
9"-2 WRT-X EPI-X EPI-Y EPI-XY EPI=1 EPI=2 WRT-X",
1" *10**6 RTIO U-IN."//)
2002 FORMAT(" NO. OF LIFTS/OR TIME SPANS- ",15/" ANALYSIS ",
1"CYCLE NO.",9(1H-),15/" STRESS AND STRAIN AFTER--",E7.2,
2" DAYS"/" APPROXIMATION NO?",10(1H-),15/" ELEM ",
3"CENTROID-IN. ",18(1H-),18(1H-),18(1H-),18(1H-),
4"MICROSTRAINS",14(1H-),18(1H-),18(1H-),18(1H-),
5"X-ORD Y-ORD SIG-X SIG-Y SIG-XY SIG=1 SIG=2 ",
6"WRT-X EPI-X EPI-Y EPI-XY EPI=1 EPI=2 WRT-X ",
7"*10**6 RATIO"//)
2003 FORMAT(14,1X,2F7.1,5F8.1,1F7.2,5F8.1,1F7.2,2F7.3,1F5.2)
2001 FORMAT(14,1X,2F7.1,5F8.1,1F7.2,5F8.1,1F7.2,2F7.3,1F5.2)
2007 FORMAT(///" LIFT NO. ",18/" LIFT ANAL NO.",18/"
1" TIME(DAYS)-----",F10.2/" TIME INCR(DAYS)-",F10.2
2,///(" ELEM XE(1) ANGLE")//)
END
SUBROUTINE STRESS
PARAMETER MXN=576,MXE=475
CHARACTER NX7*6(7),NY7*6(7)
COMMON NUMP,NUMEL,NUMPC,N,VOL,TEMP,MTYPE,LAY,NUMN,NANAL,NP,OVER
1,NDT,NCOUNT,TI,DT,DTI,T1,TL,XC,YC,ST(3,10),TIMLA(27),NUME(27),TIM,
2TTT(15),NUMOL,TIME,NNAL,NLAY,ISC,EX,EY,DASH,ANAL(200),NANAL,TLAST
3,RRR(5),ZZZ(5),NFLAG=TL1
COMMON /MATARG/ E(30,6,8),RO(8),EE(5),MED(15),CIC(20,4,8),
1CC(4,8),NCREEP(8),SC(30,2,8),NSC
COMMON /ELEARG/ IX(MXE,5),MTAG(MXE),SIG(MXE,5),TOLD(MXE),
1DE11(MXE),DE12(MXE),DE21(MXE),DE22(MXE),DSIG(6),CCO(4),CCC(4)
2,EE5(MXE,2),EPS(6),SEAP(MXE),NE7(7),NX7,NY7,TEMPE(MXE)
COMMON /PRSARG/ IBC(100),JBC(100),PR(100)
COMMON /ORDARG/ R(MXN),Z(MXN),LR(MXN),UZ(MXN),CODE(MXN),T(MXN)
COMMON /BANARG/ MBAND,NUMBLK,B(120),IA(120,60)
COMMON /LS4ARG/ I,J,K,S(10,10),C(3,3),D(3,3),H(3,3),P(10),LM(4),
1 F(3,3)
C*****COMPUTE ELEMENT STRESSES*****
DO 50 I=1,6
50 DSIG(I)=0.0
IF (IX(N,3)-IX(N,2)) 90,80,90
C*****FOR ONE-D ELEMENT*****
80 I=IX(N,1)
J=IX(N,2)
DX=R(J)-R(I)
DY=Z(J)-Z(I)
XL=SQRT(DX**2+DY**2)
DU=B(2*J-1)-B(2*I-1)

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DV=B(2,J)-B(2,I)	00011800
DL=DV*DY/XL+DU*DX/XL	00011800
DSIG(1)=DL*E(1.2,MTYPE)/XL+SIG(N,1)+SIG(N,4)	00011800
IF (NCOUNT-NP) 85,84,84	00011800
84 SIG(N,4)=DSIG(1)	00011800
SIG(N,1)=0.	00011800
85 XC=0.0	00011800
YC=0.0	00011800
GO TO 320	00011900
C.....FOR TWO-D ELEMENT.....	00011901
90 CALL QUAD	00011900
DO 120 I=1,4	00011900
II=2*I	00011900
JJ=2*II(N,I)	00011900
P(II-1)=B(JJ-1)	00011900
120 P(II)=B(JJ)	00011900
DO 150 I=9,10	00011900
P(I)=0.0	00011900
KK=I-1	00012000
DO 150 K=1,KK	00012000
150 P(I)=P(I)-S(I,K)*P(K)	00012000
D(1,1)=0.	00012000
D(2,1)=0.	00012000
D(3,1)=0.0	00012000
DO 170 I=1,3	00012000
DO 170 K=1,10	00012000
170 D(I,1)=D(I,1)+ST(I,K)*P(K)	00012000
THETA= SIG(N,3)/57.296	00012000
CO=COS(THETA)	00012100
SS=SIN(THETA)	00012100
C2=CO*CO	00012100
S2=SS*SS	00012100
SC0=SS*CO	00012100
DSIG(1)= SIG(N,4)*C2+SIG(N,5)*S2-DSIG(1)	00012100
DSIG(2)= SIG(N,4)*S2+SIG(N,5)*C2-DSIG(2)	00012100
DSIG(3)=(SIG(N,4)-SIG(N,5))*SC0-DSIG(3)	00012100
DO 180 I=1,3	00012100
DO 180 K=1,3	00012100
180 DSIG(I)= DSIG(I)+ C(I,K)*D(K,1)	00012200
C.....OUTPUT STRESSES.....	00012201
C.....CALCULATE PRINCIPAL STRESSES.....	00012202
AA=(DSIG(1)+DSIG(2))/2.	00012200
BB=(DSIG(1)-DSIG(2))/2.	00012200
CR= SQRT(BB**2+DSIG(3)**2)	00012200
DSIG(4)=AA+CR	00012200
DSIG(5)=AA-CR	00012200
IF ((BB.EQ.0.0).AND.(DSIG(3).EQ.0.0)) GO TO 320	00012200
DSIG(6)=ATAN2(DSIG(3),BB)/2.	00012200
DSIG(6)=57.296*DSIG(6)	00012200
320 RETURN	00012300
END	00012300
S EXECUTE	00012300

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\$	LIMITS	100,52K,,20K	00012380
\$	FILE	01,X1R,10L	00012380
\$	FILE	02,X2R,10L	00012380
\$	FILE	07,D1S,10L	00012380
\$	TAPE9	04,A2D,,0517,,	00012380
\$	TAPE9	03,A1D,,,DWORSHAK-STRESS	00012380
\$	MSG2	SAVE 03,CAMRBELL,800046,DWORSHAK-STRESS	00012390
\$	DATA	20	00012400
\$	SELECTA	INPUT1	00012410
\$	BREAK		00012420
\$	CONVER		00012430
\$	LIMITS	,,,8K	00012440
\$	SYSOUT	0Y	00012450
\$	FILE	IN,D1R	00012460
\$	ENDJOB		00012470

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Liu, Tony C

Verification of temperature and thermal stress analysis computer programs for mass concrete structures / by Tony C. Liu, Roy L. Campbell, Anthony A. Bombich. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1979.

47, [59] p. : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; SL-79-7)

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References: p. 47.

1. Computer programs. 2. Concrete dams. 3. Concrete structures. 4. Dworshak Dam. 5. Mass concrete. 6. Temperature. 7. Thermal stresses. I. Bombich, Anthony A., joint author. II. Campbell, Roy L., joint author. III. United States. Army. Corps of Engineers. Walla Walla District. IV. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; SL-79-7.
TA7.W34m no.SL-79-7